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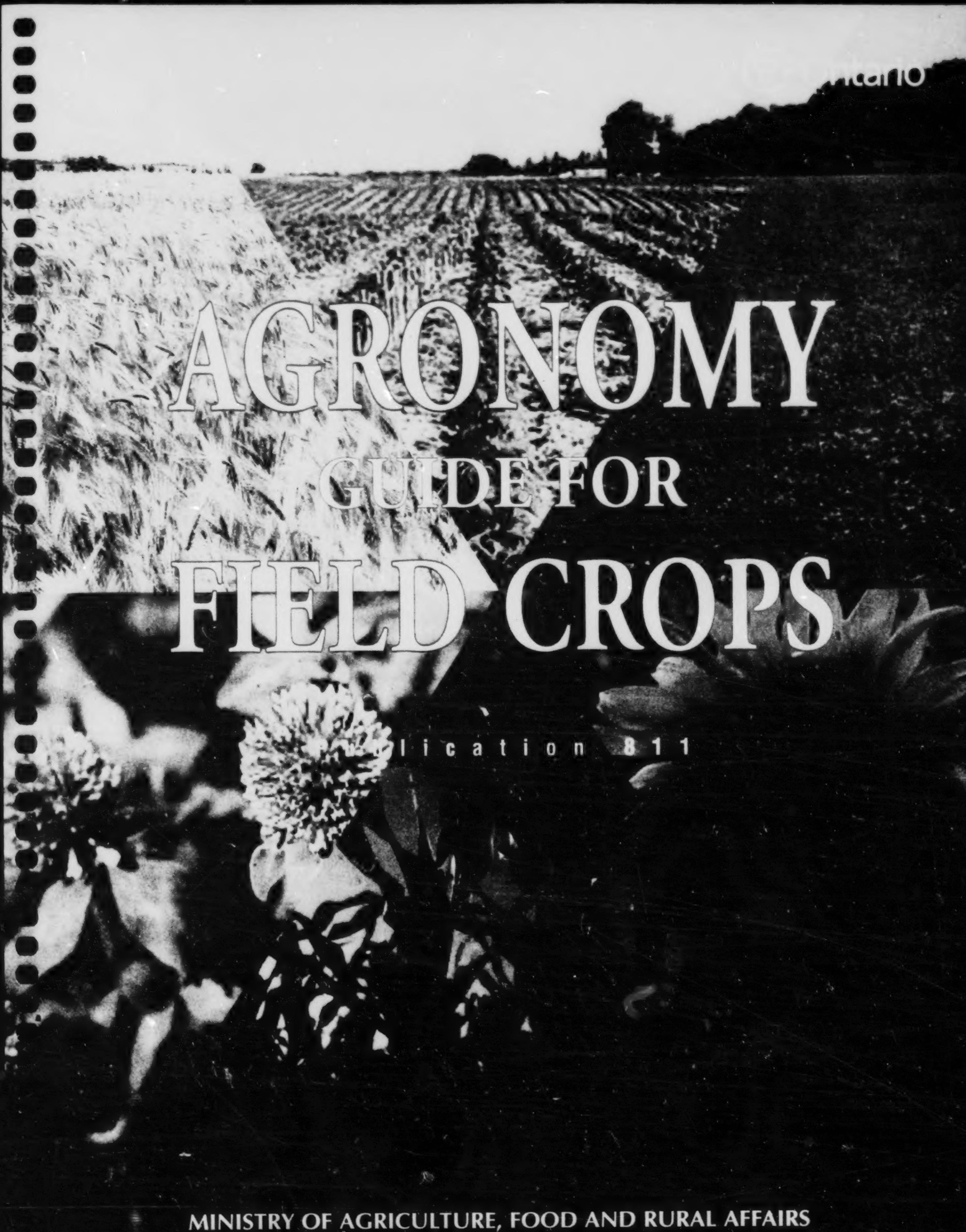

AGRONOMY GUIDE FOR FIELD CROPS

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MINISTRY OF AGRICULTURE, FOOD AND RURAL AFFAIRS

Agronomy Guide for Field Crops

Publication 811

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Introduction

This guide is designed to be a reference for detailed information related to the production, pest management, harvest and storage of the field crops produced in Ontario. Its content exceeds that of its forerunner, OMAFRA Publication 296, *Field Crop Recommendations*, which is no longer in print. This is the first edition of this publication.

Basic crop scouting procedures and the proper initiation of on-farm trials are outlined in Chapter 1. Chapter 2 discusses various aspects of soil management and fertilizer uses that are common to all field crops in Ontario. The remainder of the publication focuses on each field crop commodity separately, dealing with tillage, variety selection, planting, fertility, harvesting, storage, weed control, insect and disease information and other crop problems specific to each commodity. A final chapter on stored grain management focuses on proper grain storage and the control of stored grain insect pests. Colour photos have been included as an additional diagnostic tool.

Please note that this book does not provide recommendations regarding specific pesticide products for the control of insects, diseases and weeds. For such information, refer to OMAFRA Publication 812, *Field Crop Protection Guide*, and Publication 75, *Guide to Weed Control.*

Updates to this publication will be made available on the OMAFRA Web site at www.gov.on.ca/OMAFRA/english.

1. Field Scouting and On-Farm Trials

Field Scouting

Crop scouting is the regular examination of fields to accurately identify yield-limiting factors during the growing season. Scouting provides an objective summary of the crop condition and pest situation in a field. Factors limiting the productivity of a field often arise suddenly and must be corrected quickly to preserve the full yield potential of the crop.

Every field season should begin with the recording of vital field information on soil fertility and crop inputs on a field record form similar to the one provided on page 9. This information, combined with regular field scouting, accurate identification and diagnosis of problems and a record of those observations, makes for a successful crop monitoring program. Field scouting forms are provided on page 10. The information obtained from field scouting is useful in determining if any immediate actions should be taken. The information recorded is also useful for future reference to avoid problems in subsequent years. For example, a disease such as soybean cyst nematode impacts both crop rotation and variety selection when soybeans are grown again in the same field. Accurate records will aid in the decisions required to help manage this disease.

Timing of Field Scouting Operations

Early recognition of pests and their control will minimize their economic impact on the crop. Under each commodity chapter within this publication, crop scouting calendars illustrate the timing associated with the common crop insects and diseases found in Ontario. It is important to monitor fields consistently and frequently since pest dynamics can change rapidly throughout the season. As optimum plant populations are critical for achieving good yields, evaluate crop stands within 1–2 weeks of plant emergence. Early in the growing season, scout weekly. When approaching a control threshold, such as the application of a postemergent herbicide or a fungicide, fields may require scouting daily. Later in the season, biweekly scouting is normally sufficient. Keep in mind that some insects and diseases occur later in the season and may approach control thresholds in a matter of days. Examples of such pests include armyworm, grasshoppers and stalk rots. If field and weather conditions favour these later-season pests, scouting should continue weekly.

Scouting Tools and Techniques

Tools used to monitor crop development and pests vary with the crop and the pest. Basic field scouting equipment includes:

- a clipboard with field scouting forms or a notebook
- field maps
- a shovel
- a pocketknife
- plastic and paper bags for collecting specimens
- a 10X hand lens and a sampling frame (i.e., hula hoop)

Other tools could include aerial field images, a camera, labels for identification, reference guides, a sweep net, vials and isopropyl alcohol, sticky cards or traps to detect insect pests, a GPS unit to mark the location, flagging material, etc. It is also wise to wear appropriate clothing for protection from the sun and from unknown risks such as poisonous plants and mosquitoes. Be aware of recent pesticide treatments applied to the field and obey re-entry intervals indicated on product labels.

When scouting for insects that move too quickly in the canopy to be spotted at a glance, it is sometimes easier to use the beat cloth or sweep net. A beat cloth can be spread on the ground between two rows of crop. The crop can then be pulled over the cloth and shaken vigorously so that any insects on the plant are dislodged onto the cloth. The insects can then be easily identified and counted.

A sweep net is the preferred scouting method when evaluating a solid stand crop like alfalfa or solid stand soybeans. Standard 37-cm (15-in.) diameter sweep nets are available commercially through the various companies listed in Appendix A, *Insect-Monitoring Equipment Supply Companies*, on page 257. While walking through the canopy, swing the net from side to side in a pendulum-like motion, across the top of the canopy so that the top of the net is at the top of the canopy. Avoid dirt collecting in the net by not digging into the ground during the sweeping procedure. Bringing the net across and back to the home position is considered one sweep (e.g., sweep right to left and back again for one sweep). After 20 sweeps, quickly close the top of the net by grasping it just below the opening. Slowly open the net, remove any plant debris collected and count the number of insects that have

Table 1-1.
Number of Recommended Sampling Locations Based on Field Size and Pest

Field Size		Number of Sampling Locations	
(hectares)	(acres)	Insects/ Diseases	Weeds
Up to 8	Up to 20	5	10
8 to 12	20 to 30	8	15
12 to 16	30 to 40	10	15

been captured. Though sweep nets will not give an absolute number, they will provide a relative estimate of insect pressures, allowing for a quick assessment of the presence of a particular insect.

Number of Sampling Locations

Scouting involves walking through a field and stopping at a number of locations to make observations. The number of sampling locations in a field depends on factors such as field size, crop, pest, etc. The general number of sampling locations for a range of field sizes is displayed in Table 1-1, *Number of Recommended Sampling Locations Based on Field Size and Pest,* above. For scouting purposes, fields larger than 16 ha (40 ac) should be split into units of 16 ha (40 ac) or less.

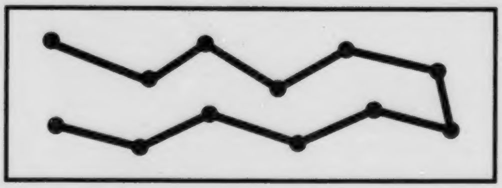
Scouting Pattern

There are a few factors to consider when determining what scouting pattern to follow in your field.

- Use a scouting pattern that includes changes in variety/hybrid, soil type, past cropping history, fertilizer/manure application and any other factors that can affect plant growth. The pattern should cover all parts of the field and should vary each time the field is scouted. See Figure 1-1, *Scouting Patterns,* right.
- Sampling locations should be selected on the basis of a predetermined random pattern, as opposed to factors such as crop appearance, etc.
- Start scouting at least 20 m (66 ft) into a field. Outside rows and headlands should be avoided in the scouting pattern unless there are specific reasons for sampling these areas.

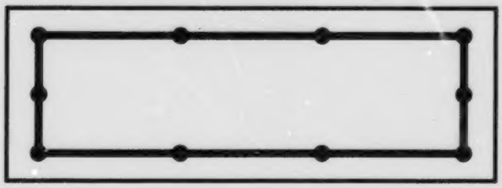
Determining Plant Population and Pest Infestation Levels

Plant population and some pest infestation levels are determined by making counts in areas of a given size and then multiplying that number by a factor to obtain the population per acre. For row crops, plant population can be calculated by counting the number of plants in a thousandth of an acre and then multiplying the count by 1,000 to obtain the number of plants per acre. Table 1-2, *Length of Row Required for a Thousandth of an Acre at Various Row Widths,* on page 3, lists the row length equal to a thousandth of an acre at various row widths.



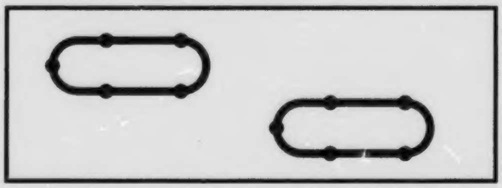
Pests Uniformly Distributed Across the Field
When scouting for pests or problems that you expect to occur uniformly in the field or for pests and problems whose distribution pattern is unknown, distribute the sampling locations evenly across the field as shown above. This pattern is also appropriate for soil sampling.

Pests that fit this scouting pattern include corn rootworm, European corn borer and stalk rots.



Pests Expected in Headlands or Outside Rows
When scouting for pests or problems that you expect to appear on headlands or in outside rows, distribute the sampling locations evenly around the edges of the field, as shown above.

Pests and problems that fit this scouting pattern include armyworm, spider mites and soil compaction.



Pests Developing in Specific Areas of the Field
When scouting for pests or problems that you expect in particular parts of a field, concentrate sampling locations in areas where the problem or pests are most likely to be found, as shown above.

Pests that fit this scouting pattern include Phytophthora root rot in damp clay soils and black cutworms in weedy patches.

FIGURE 1-1.
Scouting Patterns

Table 1-2.
Length of Row Required for a Thousandth of an Acre[1] at Various Row Widths

Row Width		Length of Row Equal to $^{1}/_{1,000}$ acre	
centimetres	inches	metres	feet
38	15	10.6	34 ft. 10 in.
51	20	8.0	26 ft. 1 in.
56	22	7.3	23 ft. 10 in.
71	28	5.7	18 ft. 8 in.
76	30	5.3	17 ft. 5 in.
81	32	5.0	16 ft. 4 in.
86	34	4.7	15 ft. 5 in.
91	36	4.4	14 ft. 6 in.
97	38	4.2	13 ft. 9 in.

[1] To obtain the number of plants per hectare, multiply the number of plants per acre by 2,470.

To determine plant population in narrow-row crops or weed infestation levels, a sampling frame with a known area can be placed on the ground for the counts. This can be accomplished using a square frame (e.g., 50 cm x 50 cm = 0.25 m^2) or circular frame (e.g., a hula hoop). The "hula" hoop method is displayed in Table 1-3, *Determining Plant and Pest Populations Using a "Hula" Hoop*, right. By using the table, the number of plants/ha (plants/ac) can then be determined by measuring the diameter of the hoop, counting the number of plants that are found within the hoop and multiplying that number by the predetermined factor listed for the inside-hoop diameter.

Many insect action thresholds are expressed as the average number of insects per plant, per sweep, per square metre or per foot of row. Some may also be based on a percentage of defoliation or damage. Regardless of the method used, at least 10 random counts should be taken in each field to determine average populations.

Recording Field Observations

Field scouting records are an essential tool to use for both current and future management decisions. Using a field scouting form will facilitate and standardize the recording of field observations. Once recorded, the scouting data should be added to the field record files. Computer software is also available to record and manipulate data from field observations.

Information to be recorded should include:

- field location and scouting date
- growth stage and condition of the crop
- hybrid/variety planted and whether it's resistant or transgenic
- flowering, tasselling, heading dates
- weather conditions
- soil conditions
- weed species present, location and population
- diseases present, location and population
- insects present, location and population
- crop damage
- field map
- results of scouting procedures performed
- action required

Table 1-3.
Determining Plant and Pest Populations Using a "Hula" Hoop

Inside Diameter of Hoop in Centimetres (inches)	Square Area in Metre^2 (ft^2)	Factor by Which to Multiply the Number of Plants Within the Hoop to Equal:	
		Plants per Hectare	Plants per Acre
91 (36)	0.65 (7.0)	15,385	6,165
84 (33)	0.55 (6.0)	18,182	7,334
76 (30)	0.45 (4.9)	22,222	8,874
69 (27)	0.37 (4.0)	27,027	10,956
61 (24)	0.29 (3.2)	34,483	13,865

Sample Handling and Submission for Diagnosis or Identification

It may be difficult to identify a pest or field problem, or you may require diagnosis and assistance. In these situations, send samples for analysis to diagnostic laboratories. For more information on how to take proper samples, where to obtain sample submission forms and diagnostic service fees, see Appendix L, *Diagnostic Service*, on page 267.

Using Growing Degree Days and Crop Heat Units

Growing Degree Days

Growing degree days, or GDDs, are used to estimate the growth and development of plants and insects during the growing season. Insect and plant development are very dependent on temperature. As an organism develops over a growing season, its development is closely related to the daily accumulation of heat. A certain amount of heat is required to provide enough energy for the organism to move to the next development stage, for example, the emergence of a new leaf on a corn plant or the first flight of European corn borer adult moths. The amount of heat required to move to the next development stage remains constant from year to year, but depending on weather conditions, the amount of actual time can vary. Each organism has a minimum base temperature or threshold below which development does not occur. These base temperatures have been determined experimentally and are different for each organism. GDD information can be very useful for predicting crop and insect development.

To calculate GDD, first determine the mean temperature for the day. This is usually done by taking the maximum and minimum temperatures for the day, adding them together and dividing by 2. The base temperature is then subtracted from the mean temperature to give a daily GDD. If the daily GDD calculates to a negative number it is made equal to zero. Each daily GDD is then added up (accumulated) over the growing season.

Some Ontario crops still use the GDD system while others have moved to the crop heat unit system described in the next section. Field crops that still use the GDD system are cereals (Base: 0), alfalfa (Base: 5) and canola (Base: 5).

Confusion has been created over the years by the terminology used to describe growing degree days. In Ontario, the terms "growing degree days" (GDD) and "crop heat units" (CHUs) are used, but they represent two very different, temperature-dependent, development models. The crop heat units calculation now used in Ontario is identical to the traditional corn heat units calculation, with the name change reflecting its now broader application to other crops. Growing degree days are sometimes referred to as "degree days" or the "degree days averaging method." Some jurisdictions also use the term "heat units" interchangeably with "degree days."

Crop Heat Units

Crop heat units (CHUs) are based on a similar principle to growing degree days. CHUs are calculated on a daily basis, using the maximum and minimum temperatures, yet the equation that is used is quite different. There are separate calculations for maximum and minimum temperatures. The maximum or daytime relationship uses 10°C (50°F) as the base temperature and 30°C (86°F) as the optimum because warm-season crops do not develop at all when daytime temperatures fall below 10°C, and develop fastest at about 30°C. The minimum or nighttime relationship uses 4.4°C (40°F) as the base temperature and does not specify an optimum temperature because nighttime minimum temperatures very seldom exceed 25°C (77°F) in Ontario. The nighttime relationship is considered a linear relationship, while the daytime relationship is considered a non-linear one because crop development peaks at 30°C (86°F) and begins to drop at higher temperatures. Daily crop heat units are calculated by using the average of the two daily values from the equations below or can be read from the matrix in Table 3-8, *Daily Crop Heat Unit Accumulations Based on Maximum and Minimum Temperatures*, on page 55.

Growing Degree Day Equation

The GDD equation used by OMAFRA is as follows:

$$\text{Daily GDD} = \frac{\text{Tmax} + \text{Tmin}}{2} - \text{Tbase}\text{, where:}$$

Tmax = the daily maximum air temperature

Tmin = the daily minimum air temperature

Tbase = the GDD base temperature for the organism being monitored

Example

Maximum Temperature: 28°C
Minimum Temperature: 15°C
Pest: European corn borer
Base: 10

Calculation

$$\text{Daily GDD} = \frac{28 + 15}{2} - 10 = 11.5$$

Therefore: 11.5 growing degree days were accumulated for that day for the European corn borer GDD model.

There are four factors to consider when comparing GDD accumulations from various sources or regions.

1. Are the base temperatures used in the equations the same?

Different organisms have different base temperatures used to calculate GDDs: 150 GDD at base 10 does not equal 150 GDD at base 0.

2. Are the start dates for the accumulations the same?

Generally, GDD accumulations start on April 1 each year, but some insect GDD models start at the emergence of a specific life stage. This is referred to as a biofix.

3. Are the equations used to calculate the daily GDD the same?

Many modifications to the simple GDD calculation have been developed over the years and may be referred to generally as degree days.

4. Are the temperatures used in degrees Celsius or Fahrenheit?

GDD accumulations will vary significantly, depending on whether they are being tracked in Celsius or Fahrenheit. GDD models have been designed specifically for use in one or the other and cannot be interchanged without making conversions.

Calculating Daily CHU

The following equation is used to calculate a daily CHU for a site:

$$\text{Daily CHU} = \frac{\text{Ymax} + \text{Ymin}}{2}, \text{ where:}$$

$$\text{Ymax} = (3.33 \times (\text{Tmax}-10.0))-(0.084 \times (\text{Tmax}-10.0)^2)$$

(If values are negative, set to 0)

Tmax = Daily maximum air temperature (°C) (measured from midnight to midnight) (Accuracy should be <0.25°C)

$$\text{Ymin} = (1.8 \times (\text{Tmin}-4.4))$$

(If values are negative, set to 0)

Tmin = Daily minimum temperature (°C)

For more information on crop heat units, refer to the OMAFRA Factsheet, *Crop Heat Units for Corn and Other Warm-Season Crops in Ontario*, Order No. 93-119, or visit the OMAFRA Web site at www.gov.on.ca/OMAFRA/english/crops.

On-Farm Trials

On-farm testing of new production techniques provides an opportunity for growers to evaluate new methods under controlled conditions without investing a large amount of acreage or costs. In this manner, new techniques can be investigated for adaptability to each individual's farming situation. The following information will provide a framework for making these evaluations in comparison to the present methods and techniques of production being used.

Standardization in on-farm plot design and set-up will allow for simple comparison of new technologies with those presently used on the farm. Standardization of plots will aid implementation, data collection and analysis, and will hopefully reduce the variation (error) that can occur with field scale plots.

Site Selection to Reduce Variability

Trial Positioning

If a field site has variations in elevation, other topography issues or obvious soil-type variation on visual inspection, position the plot to avoid these areas (see Figure 1-2, *Orientation of Treatments to Field Topography*, right).

All plots should be located in fields where the intended plot area was treated as a single field unit in previous years (see Figure 1-3, *Locating On-Farm Trials in Relation to Previous Year(s) Cropping Practices*, right).

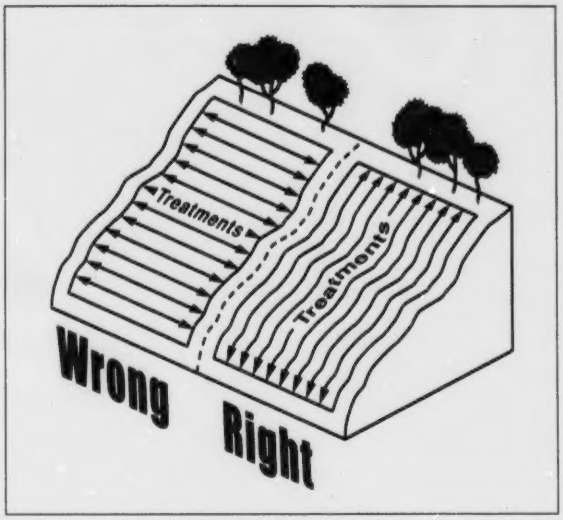


FIGURE 1-2.
Orientation of Treatments to Field Topography

This would include the same crop, herbicide, fertility, manure application programs or other agronomic practices. This will ensure that no underlying variation from previous years can cause inconsistencies in the plot results this year.

Orientation of Replications

Where possible, plots should be located perpendicular to known sources of potential trial variation such as tile lines, primary tillage dead furrows, gullies or low spots that cut across the plot area, as shown in Figure 1-4, *Orientation of Trial Treatments in Relation to Tile Lines or Other Potential Sources of Variation*, on page 6. The intention is to reduce variation over the whole plot and where variation can not be removed, to at least have it occur equally across all treatments. Otherwise variation may affect only one or a few treatments in a trial leading to incorrect conclusions from results. It is understood that this alignment of plots may not be possible.

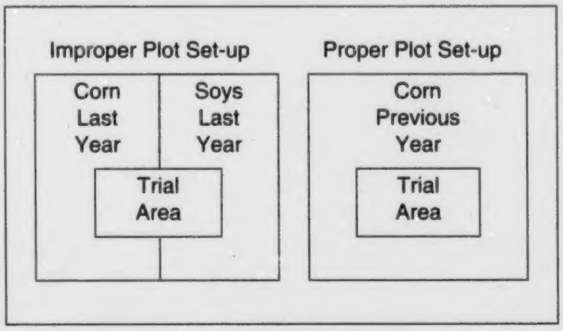


FIGURE 1-3.
Locating On-Farm Trials in Relation to Previous Year(s) Cropping Practices

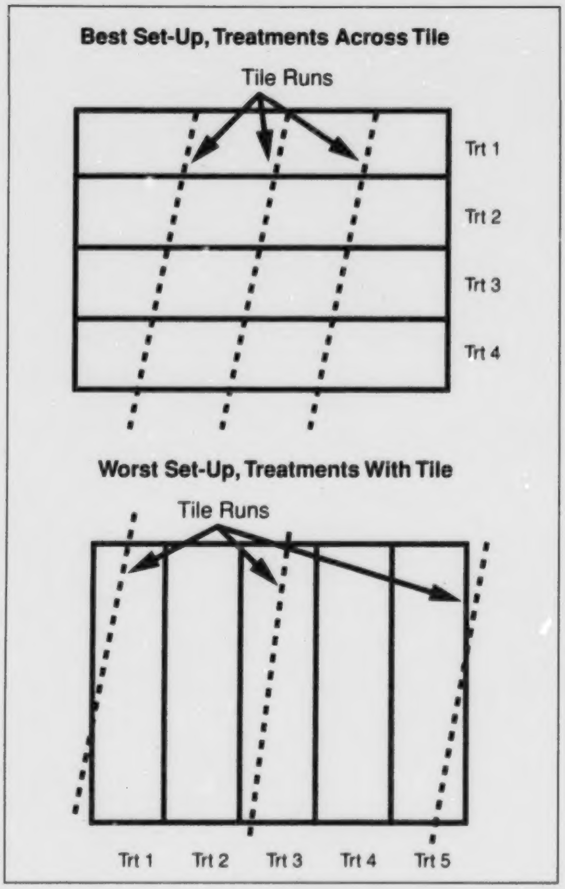

Best Set-Up, Treatments Across Tile
Tile Runs
Trt 1
Trt 2
Trt 3
Trt 4
Worst Set-Up, Treatments With Tile
Tile Runs
Trt 1
Trt 2
Trt 3
Trt 4
Trt 5

FIGURE 1-4.
Orientation of Trial Treatments in Relation to Tile Lines or Other Potential Sources of Variation

Where possible, apply herbicide, fertilizer or other inputs to the plot area perpendicular to the direction of treatments, as shown in Figure 1-5, *Direction in Which Inputs Should Be Applied on Plots to Reduce Inherent or Applied Variation*, right. Where not practical, the application of inputs to the whole plot area should be done as accurately as possible. This will help reduce the potential of introducing variation into the plot because one or a few treatments received more or less fertilizer or a high or low rate of herbicide, etc., then adjacent treatments. By applying inputs perpendicular to treatments, all treatments have the same opportunity to experience an application error. The goal is to reduce inherent or applied variation in the whole plot so that the treatment differences observed are real and not due to some underlying variation.

Trial Design

Trials that are established with fewer treatments and more replication provide better results by reducing variation. Trials having three to four replicates are preferred, while trials having only one replicate are least desirable for reducing variation. Where replication is not possible, duplication of a single treatment within the plot will help provide an estimate of the variation that may be present at a site.

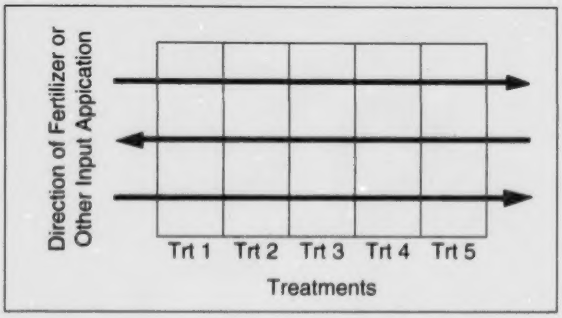


FIGURE 1-5.
Direction in Which Inputs Should Be Applied on Plots to Reduce Inherent or Applied Variation

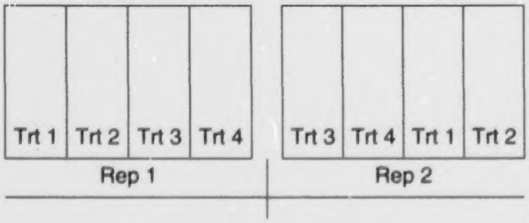
Placing a trial in the middle of a field has benefit. This reduces the potential for variation such as compaction, weed pressures, change in soil pH, etc., that may be present near field edges. Also, if the plot is placed in the middle of a field, the edges of the plot can be used as check strips for the plot (see the third plot layout in Figure 1-6, *Three Potential Plot Layouts*, on page 7). A single treatment equal to the overall field program (check) can then be included in the middle of the trial, providing three check strips for estimating the plot variation.

Depending on the type of plot being conducted, it may be necessary to account for potential edge effects. The plot must be wide enough that the region of an individual treatment where assessments are going to be taken will not be influenced by adjacent treatments.

The layout of an on-farm trial is important in ensuring that meaningful data can be collected, interpreted and reported.

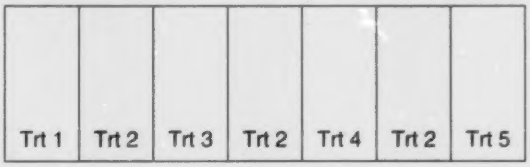
Treatment Selection

On-farm trials should be kept simple. Choose a small number of treatments to compare that endeavour to answer a limited number of questions. The more questions that a trial is asked to answer, the more difficult it will be to determine direct treatment effects. Treatments should accurately reflect a comparison of new and existing technologies or methods. Design the trials carefully to ensure that they are answering the questions being asked and that the treatments chosen can generate those answers.

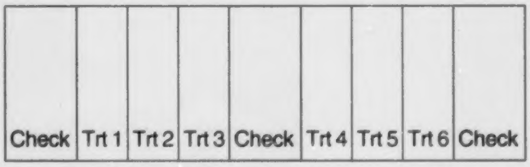


Two-Replicate Plot

1. Two-replicate plot where all treatments are repeated. Replicates can be placed beside or behind each other. This layout can be expanded for 3–4 reps.



2. Plot with a single treatment (in this case, Trt 2) repeated between each treatment to provide a measure of field variability.



3. In this plot layout, the check plot is repeated at the ends and in the middle. This provides an estimate of the amount of field variability present across a field since the yield or treatment result for the check plots can be compared for consistency across the width of the trial area. If the results of these treatments vary widely, the trial may need to be discarded, since the variability is too high.

FIGURE 1–6.
Three Potential Plot Layouts

Identify up front the types of information wanted from the trial. From the beginning, know what data needs to be collected, how to make the assessments and when to record the data.

Plots should be kept as consistent as possible. It is important to have an accurate measure of plot size, especially the sampled or harvested area. Sampling should be consistent from plot to plot and should occur across all plots in the shortest time possible. Where an individual on-farm trial is a portion of a larger project with several locations, try to use the same input types and equipment. This removes the possibility of input source, equipment and/or field operation from contributing to trial variation.

Data Collection

Data to be recorded should be identified at the beginning of the trial, and every effort should be made to record the data in an orderly and timely manner. The type and timing of data collection will vary with the nature of trial.

Since a great deal of on-farm research and many demo trials are ultimately concerned with the yield impacts of various treatments, the method of harvest and the appropriate equipment and people involved in yield data collection should be identified.

> Communication between those involved in trials is important to ensure that an entire season's work is not lost because a weigh wagon or the right people are not present when the combine is in the field.

In general, the data that should always be recorded for an on-farm trial include:

- planting date
- harvest date
- cultivar or hybrid
- sampling/assessment dates (tissue, soil samples, height, silking/flowering dates, etc.)
- soil type, soil condition at planting
- tillage system used
- fertility amount, type, time and method of application
- weed control program or other inputs used
- daily temperature (minimum and maximum)
- rainfall
- notes on site with reference to any factors that could contribute to plot variation

Generic forms and other information on conducting on-farm research and demonstration trials is available on the OMAFRA crops Web pages at www.gov.on.ca/OMAFRA/english/crops.

Always make a plot map showing the type and placement of treatments. This is valuable to the grower and any person assisting with the trial. Include reference and distances to permanent markers such as fence rows, buildings, trees, etc. Include an indication of direction. See sample forms at the end of this book.

Data Assessment

Check plots are necessary in trials so the amount of variability can be evaluated. It is important to review trial results in light of the variation present in the trial area. The error variation present in a trial comes from soil type, fertility, topography, drainage and/or other

Strip Trial Variability Example

The following charts give examples of hybrid strip trial harvests where the amount of variability is different despite average yields across the checks being equal.

Plot Layout of a Typical Corn Hybrid Strip Trial

Tests	←Hybrids→								
	CHECK 1 t/ha (bu/ac)	A	B	C	CHECK 2 t/ha (bu/ac)	D	E	F	CHECK 3 t/ha (bu/ac)
Example 1	7.03 (112)				7.97 (127)				6.65 (106)
Example 2	8.28 (132)				6.34 (101)				7.03 (112)
Example 3	7.15 (114)				6.96 (111)				7.53 (120)

Example Calculations to Determine If Plot Variability Is Within Suitable Limits

	Example 1		Example 2		Example 3	
	t/ha	bu/ac	t/ha	bu/ac	t/ha	bu/ac
Yield 1	7.03	112	8.28	132	7.15	114
Yield 2	7.97	127	6.34	101	6.96	111
Yield 3	6.65	106	7.03	112	7.53	120
Total Yield	21.65/3	345/3	21.65/3	345/3	21.65/3	345/3
Average Yield	7.21	115	7.21	115	7.21	115
Range (10%)[1]	6.49 to 7.93	103.5 to 126.5	6.49 to 7.93	103.5 to 126.5	6.49 to 7.93	103.5 to 126.5
Acceptable (Y/N)	no	no	no	no	yes	yes

[1] Calculation of range around average yield: t/ha: 7.21 x 0.9 = 6.49 and 7.21 x 1.1 = 7.93
bu/ac: 115 x 0.9 = 103.5 and 115 x 1.1 = 126.5

In this case, Examples 1 and 2 would be considered to have too much variability across the trial, and the data would be rejected. Example 3 has all the Check plot yields within the 10% range of the average yield suggesting that variation is minimal or evenly distributed over the plot area. This data would therefore be accepted. Differences seen between other hybrids in the strip trial could be considered real.

factors that are not uniform across the whole trial area. Therefore, the difference in treatment results (e.g., yield) may be partially due to random variation in the trial area and not solely to treatment (e.g., hybrid) differences.

By comparing the amount of variability between the check plots in a trial, you can determine if the treatment differences observed are actually due to treatment (e.g., hybrid) and not some other unrelated factor(s) (such as fertility, drainage, etc.).

If the difference in yield (or other parameter being evaluated) among the check plots is greater than +/- 10% of the average of the check plots, the variability is probably too great, and the trial results should be discarded.

If in reviewing the data from a trial, the difference in yield between two treatments (e.g., hybrids) is less than the largest difference between the checks, then it is unlikely that the treatments (e.g., hybrids) are different.

Example of Differences in Yield Between Two Treatments (Hybrid A and B)

Check #1	6.46 t/ha (103 bu/ac)
Check #2	6.84 t/ha (109 bu/ac)
Check #3	6.08 t/ha (97 bu/ac)

Difference between Check #2 (high) and #3 (low):
6.84 t/ha - 6.08 t/ha = 0.76 t/ha
(109 bu/ac - 97 bu/ac = 12 bu/ac)

Hybrid A	6.71 t/ha (107 bu/ac)
Hybrid B	6.21 t/ha (99 bu/ac)

Difference between Hybrid A and B:
6.71 t/ha - 6.21 t/ha = 0.5 t/ha
(107 bu/ac - 99 bu/ac = 8 bu/ac)

Therefore, in this case, Hybrid A would not be considered different from Hybrid B because the difference between the two (0.5 t/ha) is less than the difference between the check hybrids (0.76 t/ha).

FIELD RECORD FORM 20___

	Field I.D.				Field I.D.				Field I.D.				Field I.D.			
Acreage																
Soil Type																
Soil Fertility	pH	N	P	K	pH	N	P	K	pH	N	P	K	pH	N	P	K
Tillage																
Variety/Hybrid																
Seeding Rate																
Seeding Date																
Seed Treatment																
Fertilizer/Lime product, rate, timing																
Manure Application																
Herbicides																
Rate																
Crop Stage																
Date																
Yield																
Harvest Date																
Moisture																
Test Wt/Grade																
Notes																

Field Scouting Form

Farm: ________ **Scout:** ________ **Date:** ________ **Time:** ________

Field: ________ **Acreage:** ________ **Crop:** ________ **Plant Population:** ________

Crop Growth Stage, Height and Condition: ________

Soil Condition: ________

Weeds	Growth Stage	Pressure/Density

Insects	Stage	Pressure/ Density

Diseases	Stage	Pressure

Field Map: weeds, insects, disease patches, crop condition, including GPS coordinates

Field Scout's Comments:

Action Recommended:

Project Data Form

Grower Name: ______________________________ **Phone #** ______________

Project Title: ______________________________

VARIETY(s)	Seed Treatment(s):	Seeding Date(s):	Seeding Rate(s):

Planting Info	Details
Tillage Type:	

Soil Information	Nitrogen (ppm)	Phosphorus (ppm)	Potassium (ppm)	Magnesium (ppm)	pH	Soil Type (i.e. sand/loam/clay):
Soil Test (ppm):						

Previous Crops: Yr1 ______________ **Yr2** ______________ **Yr3** ______________

Fertilizer Application			
Analysis applied	Rate (lb/ac)	Application Method (e.g., broadcast, with seed, etc.)	Date (dd-mmm-yy)
1.			
2.			
3.			

Manure Application	Type Dairy/Beef/Swine	Rate (t/ac, gal/ac)	Date (dd-mmm-yy)	% Org. N	% Inorg. N	% P	% K
1.							
2.							

Herbicides/Pesticides

Product: ______________ **Rates : (L/ac kg/ac)** ______________ **Application Date:** ______________

Product: ______________ **Rates:** ______________ **Application Date:** ______________

Product: ______________ **Rates:** ______________ **Application Date:** ______________

	Treatments	Details	Other
1	Untreated		
2			
3			
4			
5			
6			

ON-FARM TRIALS

Plot Map

Direction:

Comments/ Other Details:

2. Soil Management and Fertilizer Use

Preserving the Soil Resource

The soils of Ontario vary greatly in their make-up due to the scraping and mixing action of glacier movement. As the glaciers melted, wind, water and time contributed to further differences in soil development. Some soils are very shallow to bedrock, others are more than 100 m (328 ft) to bedrock. The depth of topsoil varies as conditions for soil formation have varied. Intensive crop production has caused further changes in the topsoil depth. Soil erosion by wind, water and tillage has reduced the amount of topsoil in many fields. In some fields, the topsoil has been lost totally from areas. Quite commonly, deep plowing has mixed topsoil with less fertile subsoil.

The quality of many soils in Ontario has declined over the last 4 to 5 decades. Soil quality is the measure of a soil's health and its ability to resist erosion, compaction and other stresses, while maintaining economic productivity. Many factors are assessed to determine a soil's health. A healthy soil will:

- have good soil structure, resist crusting and have minimal compaction
- have an abundance of earthworms
- smell good
- readily decompose residue
- have good drainage, water movement and water-holding capacity
- encourage seedling emergence and root growth
- produce uniform crop growth and colour
- have nutrient levels, pH and organic matter in the optimal range
- have suffered little wind, water or tillage erosion, and be resistant to it

Assessing the soil quality for each field and taking steps to maintain or improve it will ensure continued productivity. Maintaining soil quality is a long-term process. Some measures are easy and relatively inexpensive to implement, while others require more effort and commitment to put in place. Table 2-1, *Maintaining or Improving Soil Quality,* on page 14, displays a variety of measures that can be used to help maintain or improve various aspects of soil quality.

It is important to keep in mind that soil and its management are part of the overall crop production system. Soil is also a central part of the agricultural ecosystem. Changes made in the crop production system over the years have far-reaching effects on all other systems. When taking steps to improve soil quality, think about the changes being made and how they may affect other components of the crop production system.

An example of this impact is demonstrated by adding a cover crop into the rotation to reduce wind erosion. The cover crop may affect the following crop by acting as a host for nematodes, by acting as a weed or by leaving a mat on the soil surface that could harbour slugs or keep the soil cool and wet. These problems can be minimized by choosing a cover crop that is a non-host, does not produce seed, is easy to kill and only protects the soil for the critical time frame.

For further information on soil management, see the OMAFRA/Agriculture and Agri-Food Canada booklet *Best Management Practices — Soil Management (1997),* Order No. BMP06.

Tillage Systems

The traditional role for tillage systems has been to provide weed control and prepare a seedbed that will give good crop stands and high yields. More recently, tillage and cropping systems have been changed to accomplish the same goals while reducing soil erosion through less intensive or no cultivation. High fuel costs and shortage of labour may also cause reduced tillage to be favourable.

The switch to a different tillage system should be based on the system's compatibility with the farm's soil types, slopes, drainage, moisture regime and temperature. The tillage system's effect on erosion control, timeliness, the potential for controlling weeds, insects and diseases and the profitability of the farm operation are also important considerations. No one tillage system is best for Ontario conditions because there is so much variability in soils, crops and climate. In fact, the tillage system may rotate with the crop. Allow for the use of the most appropriate tillage for the crop to be grown. In the following sections,

Table 2-1.
Maintaining or Improving Soil Quality

Measure	Comments
Easy/less expensive	
Use of cover crops	• Cover crops with fibrous root systems will improve soil structure. • Cover crops with tap roots can penetrate dense soil layers. • Cover crops can also provide protection from soil erosion.
Soil testing and application of fertilizer and lime	• Adequate pH and fertility will improve crop growth.
Reducing tillage and using residue management	• Using fewer tillage passes to prepare the seedbed will: • leave more residue on the surface to protect against erosion • reduce soil organic matter loss • leave soil aggregates intact to reduce crusting potential
Adding organic matter in the form of manure, biosolids, etc.	• A one-time or occasional application of organic material will help maintain organic matter but will do little to raise soil organic matter levels.
Erosion control measures	• Simple measures such as buffer strips, drop structures (rock chutes or drop pipes), tile outlet protection and strip cropping greatly reduce soil erosion.
Management changes or investment required	
Minimum tillage	• Switching to tillage implements that leave more residue on the surface will help protect the soil and improve soil structure but require investment and management changes.
No-till	• Implementing a no-till system provides maximum protection from wind, water and tillage erosion; investment in new or modified equipment and significant management changes are required.
Crop rotation including a mix of cereal, legume or grass crops	• A long-term commitment to a crop rotation that includes cereal, legume and grass crops will improve soil structure, improve the water-holding capacity and make the soil less prone to erosion.
Planting windbreaks	• Windbreaks can begin to protect soil in a few short years, and the benefits can last a lifetime.
Improving drainage	• Tile drainage will remove excess water, allowing for more timely field operations, reduced compaction potential and improved crop growth.
Adding organic matter in the form of manure, biosolids, etc.	• Regularly adding organic materials to the soil will help increase organic matter levels in the soil, improve soil structure, increase the water-holding capacity and make the soil less prone to erosion.
Implementing erosion control measures	• The use of erosion control structures such as water and sediment control basins helps protect fields from major soil loss.

each major tillage system is briefly described, giving its relative advantages and disadvantages.

The major crop chapters of this publication contain information on tillage systems specific to that crop. For further information on tillage systems, see the OMAFRA/Agriculture and Agri-Food Canada booklets, *Best Management Practices — Field Crop Production (1997)*, Order No. BMP02, and *Best Management Practices — No-Till: Making It Work (1997)*, Order No. BMP11.

Conventional Tillage

Conventional tillage is any tillage system that attempts to bury most of the previous crop residue, leaving less than 30% of the soil surface covered with residue after planting. Usually the moldboard plow is used in conjunction with a variety of other tillage implements. The principal advantages of the moldboard system are that machinery is familiar and widely available and it is adaptable to a wide range of soil conditions. Moldboard plowing increases porosity, allowing for good air exchange, root proliferation and water infiltration, especially when rainfall is above average. The increased porosity can be lost with excessive secondary tillage or in soils with poor structural stability. Many livestock producers view the moldboard plow as the most effective way of incorporating manure and breaking up sod fields.

The main weakness of the moldboard system is the high costs of equipment, fuel and labour associated with seedbed preparation. Figure 2-1, *Soil Loss Reduction With Different Percentages of Residue Cover*, on page 15,

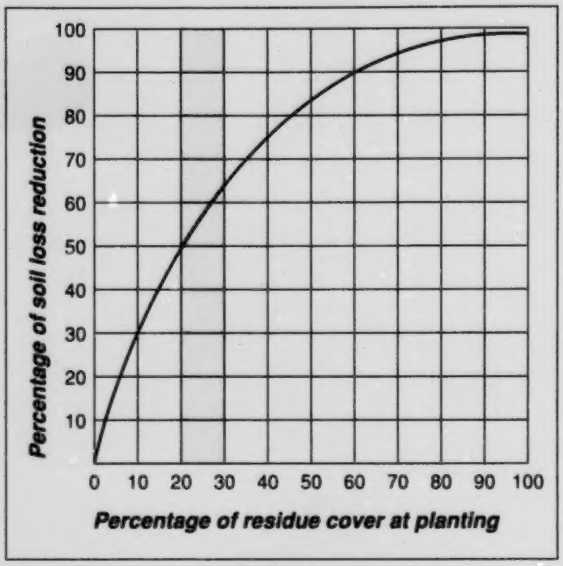


FIGURE 2-1.
Soil Loss Reduction With
Different Percentages of Residue Cover

illustrates the other key weakness with moldboard plowing. With little or no residue cover, there is a high risk for soil erosion by wind and water.

Different crops leave different residue levels after harvest, generally increasing as you progress from soybeans to small grains to corn. Perennial pasture and hay crops (sod), because of the plant density, growth habit and length of establishment, offer the greatest soil coverage and are the most effective in preventing erosion. Table 2-2, *Average Percentage of Residue Cover With Different Tillage Systems and Residue*, on page 16, explains the effect of tillage systems and previous crop on residue cover.

Fall Mulch Tillage

Mulch tillage systems are designed to leave more previous crop residue on the soil surface, giving more protection against erosion than does the moldboard plow. The chisel plow has been the most widely adopted mulch tillage tool in Ontario, with tandem and offset discs also being used extensively in some areas of the province.

Chisel plowing with twisted shovel teeth will make the soil quite ridged in the spring. This can lead to extra costs in secondary tillage (more passes), uneven seed beds and occasionally excessive soil drying. Many of these problems can be overcome by:

- using sweep teeth on all or part of the chisel plow
- adding a levelling bar or harrows to the rear of the chisel plow
- by timely secondary tillage in the spring

Spring Mulch Tillage

A good alternative for reducing erosion and input costs is to eliminate fall tillage. Producers working on heavy soils where crop residue levels are high following corn, wheat or other crops may be apprehensive about leaving soils untouched in the fall. However, following soybeans or other crops where surface residues are light and on sandy or loamy textured soils, there is little justification for doing fall tillage on most fields in Ontario. In these situations, spring mulch tillage with cultivators, discs or combination tools can often prepare suitable seedbeds and allow conventional planting equipment to be used.

No-Till Systems

No-till systems provide the greatest opportunity to leave protective crop residues on the soil surface. They also have the greatest potential for reducing tillage costs, offset somewhat by the need to control weeds in nearly all cases with a preplant "burndown" herbicide application. Numerous options exist both in the original design and in the modifications available for row crop planters or seed drills to be considered "no-till" capable. In this publication, the term "no-till" will refer to any system that confines all tillage and seeding operations to one pass of the planting equipment regardless of the various equipment designs or modifications and regardless of the amount of in-row soil disturbance they may cause.

The success of no-till systems is often dependent on a range of factors other than the equipment design. Two of these — soil drainage and crop rotation — have a significant influence on the performance of all no-till systems.

Soil Drainage

Good internal drainage improves the probability that soils will dry and allow for timely planting of crops in a no-till system. Drainage lessens the risk that soils will become saturated and prone to poor root growth and function, especially early in the season. Producers often find it difficult to successfully no-till in fine textured soils that are not systematically tile drained.

Crop Rotation

Narrow rotations where the same crop appears with a high frequency (e.g., continuous corn) do not lend themselves to no-till regardless of what else is done

Table 2-2.
Average Percentage of Residue Cover With Different Tillage Systems and Residue

Residue cover indicated can vary by 20%. With the exception of ridge tillage, the soybean counts were taken in the fall prior to planting wheat. Overwinter decomposition could break down soybean residue much more. Data collected from across Ontario.

Typical Tillage System to Prepare Seedbed	Average Percentage of Soil Surface Covered With Crop Residue at Planting			
	Previous Crop			
	Soybeans	Corn	Cereals	Sod
No tillage	[illegible]	[illegible]	[illegible]	[illegible]
Ridge tillage	[illegible]	[illegible]	0–19%	Not Appropriate
Disc + one pass Secondary tillage	20–29%	[illegible]	30–39%	[illegible]
Disc chisel + one pass Secondary tillage	0–19%	30–39%	20–29%	20–29%
Moldboard plow + one pass Secondary tillage	0–19%	0–19%	0–19%	0–19%

Chart Summary
In general, tillage systems that depend on the moldboard plow will not achieve the minimum 30% protective residue cover on the soil surface. There is a wide variety of systems using conventional tillage tools, specialized conservation tillage equipment or a combination of both types, that are capable of offering enough residue after planting for effective erosion control. These ranges should be interpreted as indicators only and are not to be used in an absolute formula to determine residue under a particular tillage system.

correctly. Sound crop rotations, including a wider range of crops such as legumes and forages, improve soil structure and generally make no-till or reduced tillage systems more successful.

Ridge Tillage

Ridge tillage systems plant crops on raised ridges. As with no-till, the soil is not tilled between harvesting one crop and planting the next. Inter-row cultivation reforms ridges and controls weeds. Ridge tillage works best with row crops, although some producers grow cereal crops on ridges. It has been used as an entry system for no-till and has been adopted on only a very small acreage in Ontario.

Choosing a Tillage System

As previously discussed, there are many factors to consider when deciding which tillage system to use. Other considerations include:

- What will be improved by a change to the tillage system?
- Will the change in the tillage system fit into current or future cropping programs?
- How will the change be made?
- Will it require new skills or a large cash investment in new machinery?
- When will the change be made? (Is it time to replace old equipment?)

Tillage System Continuity

The tillage program used on a farm may be the same every year or it may change based on the residue from the previous crop or the crop to be grown. Some no-tillers use strictly no-till, and others use tillage before the corn crop. A common example of this is in a corn, soybean and winter wheat rotation where the soybeans and wheat are no-tilled, but the wheat stubble receives some form of tillage (a light disking, chisel plowed or moldboard plowed) in preparation for corn. Table 2-3, *Tillage System Effects on Crop Yields at Woodstock, Ontario (1996–2000)*, on page 17, shows the yield impact of tillage in no-till systems.

The first five years of this study suggest that maximum corn and soybean productivity can be achieved by chisel plowing before corn followed by no-till soybean planting. The treatment where tillage occurred only for corn (i.e., chisel prior to corn, otherwise no-till) produced corn and soybean yields that were greater than continuous no-till.

Therefore, if tillage is required to correct problems associated with long-term no-till (i.e., excessive residue cover, nutrient stratification, harvest compac-

Table 2-3.
Tillage System Effects on Crop Yields
at Woodstock, Ontario (1996–2000)

Tillage System	Corn	Soybeans	Wheat
	t/ha (bu/ac)		
Continuous fall moldboard	10.60 (169)	2.89 (43)	5.04 (75)
Continuous fall chisel	10.60 (169)	3.02 (45)	5.18 (77)
Chisel before corn (no-till soybeans and wheat)	10.54 (168)	3.09 (46)	5.04 (75)
Chisel before soybeans (no-till corn and wheat)	10.29 (164)	3.02 (45)	5.04 (75)
Continuous no-till	10.16 (162)	2.96 (44)	4.97 (74)

tion, uneven seedbed conditions, etc.), then the best time to conduct tillage is prior to corn. On loam soils similar to the soil at the Woodstock site, it appears that chisel plowing can produce yields similar to moldboard plow systems. However, on clay-textured soils similar to the soil at Winchester, moldboard plowing may be a more preferable option for conducting intermittent tillage than chisel plowing.

In a three-year cropping rotation, performing tillage once (fall prior to corn planting) did not result in subsequent no-till soybean or no-till wheat yields that were lower than where the no-till system was applied consistently each year. In fact, there is some evidence to suggest that occasional tillage (i.e., 1 year before) actually enhanced no-till soybean yields.

Remedial Tillage

Remedial tillage is intended as a fix for a problem such as rutting from harvest, wet spots, compaction, etc. Remedial tillage can be as simple as a disking to fill in heavy rutting from a wet harvest but can also include subsoiling and land levelling. This type of tillage generally has limited use and is only utilized under special circumstances. Subsoiling is further discussed in the section *Soil Compaction*, on page 25.

Land Levelling

Land levelling takes place in a controlled (laser) or uncontrolled manner. Laser levelling attempts to put a consistent slope on a virtually flat field. This, combined with erosion control measures, such as rock chutes, will move surface water safely off the field. It is done only once or twice in a grower's lifetime and is a costly operation. Uncontrolled methods attempt to level the field by scraping soil off high areas and filling in the low areas. Done on relatively flat fields, the leveller is pulled back and forth across the field.

A major disadvantage is that the extensive tillage depletes organic matter, destroys soil structure and leaves the soil susceptible to wind and water erosion. Compaction and crusting are also concerns. The depth of topsoil on the knolls is also reduced, which may lower crop yields in subsequent years.

Economics of Conservation Tillage (Production Costs)

A number of factors need to be considered when comparing different tillage systems. The costs of production for a particular system are important, but yield and erosion control must also be considered. The highest yield does not always give the greatest net return. A few bushels less per acre obtained with one tillage system may be more than offset by the lower total cost per acre.

Each system requires specific tillage and planting equipment, fertilizer and pest management as well as subtle changes in many other aspects of the crop management program. A system with lower costs is not better if soil erosion is not controlled and yields decline to the point where net profits are reduced.

In general, primary tillage costs for conservation tillage systems are lower than those that include moldboard plowing. Most conservation tillage systems have fewer field operations and thereby reduce costs. Fertilizer and seed costs are similar among systems. Herbicide costs may be higher in the initial years but usually decrease to the point where costs are similar to conventional systems. Generally, the product and rate of application for broadleaf and grass control treatments are the same for conventional and conservation tillage. Banding herbicides in ridge-till systems can result in a significant cost saving.

Fuel costs in no-till systems are less than 50% of those in the moldboard tillage system for corn, soybeans and winter wheat. Similarly, labour is reduced by over 40%. Mulch tillage systems are intermediate, depending on the specifics of the system used. Total costs per acre of the conservation tillage systems are 15% less than the moldboard system, with most of the decrease attributed to reduced costs in seedbed preparation.

There are learning costs associated with changing tillage systems. The adoption of a new system can add costs in the form of mistakes made or precautionary measures taken. But time and experience with new tillage systems that reduce soil erosion should improve the long-term yield potential and profitability of the farm.

Crop Rotation

Benefits of Crop Rotation

Crop rotation is an integral part of the crop production system. The greatest benefit to a good crop rotation is increased yields. A well-planned crop rotation will help with insect and disease control and will aid in maintaining or improving soil structure and organic matter levels. Using a variety of crops can reduce weed pressures, spread the workload, protect against soil erosion and reduce risk. Legume crops in the rotation have become more valuable with the increased cost of nitrogen. Research and experience have proven that a good crop rotation will provide more consistent yields, build soil structure and increase profit potential.

The basic rule of crop rotation is that a crop should never follow itself. Continuous cropping of any crop will result in the build-up of diseases and insects specific to that crop, and cause a reduction in crop yields. The more often that crop has been grown in the field in the past, the greater this impact will be. For example, the practice of growing two or more years of soybeans is becoming increasingly common. Perhaps the greatest impact of back-to-back years of soybeans has been the accelerated spread of soybean cyst nematode (SCN). For more information and potential yield reductions, see the section *Soybean Cyst Nematode*, on page 126. The increased number of years of soybeans in the rotation is also increasing the susceptibility of Ontario's soils to erosion. In fact, the structure of soils in corn-soybean rotations can actually be poorer than that of soils that are in continuous corn production. For example, a recent study found that erosion following an intense June rainstorm in first-year corn following 2 years of soybeans was twice as high as following corn, wheat underseeded with red clover or alfalfa. Relatively poor soil structure after 2 years of soybeans not only increased erosion susceptibility but also reduced soil porosity, that resulted in less rainwater infiltration. Reduced rainwater infiltration increases the likelihood of erosion risk, yield-reducing water ponding and/or soil moisture deficits; all of these effects can reduce crop productivity, particularly in years with weather-related stress.

The greatest benefit from crop rotation comes when crops grown in sequence are in totally different families. The two families are grasses (monocots) and broadleaves (dicots). The grasses include forages grasses, cereals and corn. Soybeans, white beans, alfalfa and canola are examples of broadleaf crops. Table 2–4, *Corn Yield Response to Rotation*, above, provides an example of the type of response to crop rotation that is possible.

Table 2–4.
Corn Yield Response to Rotation[1]

	Corn Grain Yield[2]	
	Loam (1990–95)	Clay Loam (1990–93)
Rotation	t/ha (bu/ac)	
Continuous corn	8.84 (141)	6.59 (105)
Soybean-corn	9.78 (156)	7.40 (118)
Soybean-wheat-corn	9.47 (151)	7.90 (126)
Soybean-wheat (RC)[3]-corn	10.23 (163)	8.47 (135)
Soybean-wheat (RC)-RC[3]-corn	10.35 (165)	8.28 (132)

Source: Vyn, University of Guelph

[1] On a Toledo loam near Chatham, Ontario, and on a Brookston clay loam near Maidstone, Ontario.

[2] All corn treatments were fertilized with 179 kg/ha (160 lb/ac) of N.

[3] Red clover plow-down was underseeded into wheat. "Wheat (RC)-RC" indicates that underseeded red clover was not plowed under but harvested for seed the following year and then fall plowed.

The fibrous root systems of cereal and forage crops (including red clover) are excellent for building soil structure. Studies have shown that the benefits of including wheat, and especially wheat plus red clover, may persist beyond just the following year. Underseeding red clover into wheat resulted in yield increases every year for 3 consecutive years compared to when red clover was not included in 4-year rotation systems.

In choosing which crop to grow, consider the economics of the entire rotation instead of a single crop in isolation. Also, be aware of any potential insect or disease problems that could affect crops later in the rotation. Cover crops in the rotation may also have an impact on diseases and pests, either positive or negative (refer to the section *Cover Crops*, on page 20, for potential impacts of various cover crops). Table 2–5, *Various Crop Rotations and Their Potential Negative Impacts*, on page 19, displays various crop rotations that are recommended, cautioned against or not recommended depending on their impact on the crop production system. It is not a comprehensive listing of crop problems, but it does highlight the main impacts to be aware of. More information is provided in each crop chapter.

Table 2-5.
Various Crop Rotations and Their Potential Negative Impacts

Crop to Be Grown	Previous Crop: Corn	Soybeans	Forages	Spring Cereals	Winter Cereals	Edible Beans	Canola
Corn	• yield depression • corn rootworm • European corn borer • slugs may cause damage in no-till	• European chafer (on light textured soils)	• wireworms following grassy sod	• heavy residue in no-till may delay soil drying and warming	• heavy residue in no-till may delay soil drying and warming		• may adversely affect crop growth
Soybeans	• slugs may cause damage in no-till	• yield depression • soybean cyst nematode • root diseases • degrades soil	• weed escapes may be difficult to control • slugs may reduce stand	• slugs and delayed planting could affect no-till	• slugs and delayed planting could affect no-till • spider mites following clover cover crop	• white mould • degrades soil • soybean cyst nematode (maybe)	• white mould • can adversely affect crop growth
Forages	• heavy residue may interfere with seed placement in no-till	• check for herbicide carry-over	• forage diseases could increase • autotoxicity of alfalfa				
Spring Cereals			• wireworms (following grassy sod)	• leaf diseases. • yield depression	• leaf diseases • yield depression		• may be slight reduction in growth
Winter Cereals	• increased risk of Fusarium head blight	• European chafer (on light textured soils)	• weed escapes • reduced growth no-till into quackgrass	• take-all • leaf diseases	• take-all • leaf diseases • yield depression		• may be slight reduction in growth
Edible Beans		• white mould • root rots • soybean cyst nematode (maybe)	• weed escapes • slugs in no-till	• slugs may cause damage in no-till	• slugs may cause damage in no-till	• yield depression • root rots • white mould • [illegible]	• may adversely affect crop growth
Canola	• slugs may cause damage in no-till • harvest is too late for winter canola planting • check for herbicide carryover	• white mould • check for herbicide carryover	• slugs may reduce stand		• slugs may cause damage in no-till	• white mould	• white mould • blackleg • root rots • yield depression • check for herbicide carryover

Legend:	Recommended	Caution	[illegible]

Managing Soil Organic Matter

Soil organic matter is an important component of soil. It is a key part of the nutrient cycle, holding soil moisture and soil structure. The soil organic matter pool in the soil is always changing and is similar to a bank account. Farming practices add or withdraw from the pool or account. Practices such as conservation tillage, good crop rotation, cover crops, manure and other organic material additions and controlling erosion add or maintain organic matter. Excessive tillage and soil loss withdraws from the account.

Manure and Other Organic Additions

Manure

The nutrient content of manure will be discussed in the section *Manure Analysis*, on page 38.

The following should be considered when using manure as an organic matter source:

- Manure will add organic matter but also adds nutrients. Follow the recommendations for manure application found later in this chapter.
- The organic matter content of a manure will vary depending on the type.
- The application rate will also determine the amount of organic matter added to the soil.

Biosolids and Residuals

Biosolids and residuals are another option for adding organic matter to soil. Biosolids are the organic-based materials resulting from municipal wastewater treatment processes and are regulated under Part V of the *Environmental Protection Act*. Residuals are waste materials produced by commercial or industrial processes and may be organic or inorganic in nature. Residuals applied to agricultural land are also regulated under Part V of the *Environmental Protection Act*. As with manure, the type of biosolid and rate of application will determine the amount of organic matter added to the soil. For more information, refer to the section *Biosolids and Residuals Use on Agricultural Land*, on page 43.

Cover Crops

Cover crops play an important role in Ontario by providing ground cover to reduce erosion and by adding organic matter to improve the soil. They can also perform a number of other functions.

Cover Crop Functions

Reduce Soil Erosion

Cover crops can do exactly what their name implies; used to cover and protect the soil surface from wind and water erosion. The top growth covers the soil surface while the roots bind and stabilize the soil particles. Cover crops may be planted over a whole field for erosion protection or they may be selectively planted in the most erosion-prone areas, such as sandy knolls for wind erosion, water runs or low areas for water erosion.

Table 2–6.
Cover Crop Dry Matter Production

Common Cover Crops[1]	Dry Matter Produced	
	kg/ha	(lb/ac)
Red clover (plow-down)	2,700–4,500	(2,403–4,005)
Oats	1,000–5,500	(890–4,895)
Rye	1,000–4,000	(890–3,560)
Oilseed radish	2,000–7,500	(1,780–6,675)

[1] Dry matter production can vary greatly due to a number of production factors.

Add Organic Matter

Cover crops do add organic matter, but the amount really varies depending upon the cover crop species and the conditions under which it is grown. Table 2–6, *Cover Crop Dry Matter Production*, above, gives dry matter levels (above-ground residues only) for some common cover crops established in late summer and early fall. The numbers were collected from cover crop plots in Southwestern Ontario.

These may not show as great an organic matter return as some of the cover crop work from the United States, however, it is important to consider climatic differences and how the cover crop is incorporated into the crop rotation.

Reduce Nutrient Losses

Some cover crops fix nitrogen, but many more require nitrogen to grow. Grass cover crops (such as rye) and brassicas (such as oilseed radish) are excellent scavengers of nitrogen left behind by the main crop or from manure applications. Cover crops that take up nitrogen can help to reduce nitrogen losses due to leaching. This reduces the potential for the movement of nitrates to shallow aquifers. When the cover crop is killed, the nutrients held in the plant tissues are returned to the soil and can be used by the following crop.

Improve Soil Fertility

Legume cover crops can fix nitrogen for a subsequent crop. Organic growers often include this type of cover crop in order to produce nitrogen for the rest of the crop rotation. Some cover crop species are credited with making more phosphorous available to other crops through the action of the roots. Deep-rooted cover crops can bring nutrients up from deep in the soil profile.

Reduce Pest Populations

Some cover crop species may be a non-host for a pest or may release materials that are toxic to the targeted pest. For example, many common cover crops have been rated for their ability to support root lesion and other nematode populations (see Table 2-7, *Characteristics of Cover Crops Grown in Ontario*, on page 22). Cover crops like marigolds and pearl millet do not support or allow the nematode to reproduce. Other cover crops, such as some mustards, particularly those with high glucosinilate and euricic acid levels in the plant tissue can create a "natural fumigant" through the chemical breakdown of these materials. The amount of green plant material that must be tilled into the soil for this to be effective is often difficult to achieve under field conditions. Weeds are often alternate hosts for the nematodes. Good cover crop establishment, adequate plant stand and excellent weed control within the cover crop are critical for these methods of nematode reduction/suppression to be effective.

Reduce Compaction and Improve Soil Structure

Cover crops can help reduce compaction and improve soil structure. The addition of the plant top and especially root matter helps to improve water infiltration and holding ability. It can also decrease soil bulk density. Deep-rooted cover crops can help decrease the impact of soil compaction. If deep tillage is used to combat compaction, the seeding of a cover crop can help stabilize the cracks and fissures that were created in the soil profile by the deep tillage. Growing cover crops and working in the residues improves soil structure.

Water Management

Cover crops can be grown and the residues used to mulch the crop and help reduce moisture loss.

Emergency Forage

Under adverse conditions and a shortage of forage due to drought or winterkill, some cover crop species can make quite acceptable hay or pasture.

Choosing a Cover Crop

Consideration	Comment
Growth habits	• What kind of growth habit is needed? • When is the growth required, e.g., lots of vigorous late fall growth or rapid early spring growth? • Is deep rooting important?
Overwintering	• Does the cover crop need to survive overwinter? •Would it suit the cropping schedule and soil type if the cover crop winter killed and dried out by spring ?
Control options	• Will the cover crop become a weed concern? • How is it controlled? • What options are there for control?
Sensitivity to herbicides	• How sensitive is the cover crop to herbicide residues from other crops in the rotation?
Seed cost and availability	• What is the seed cost and is the seed available in your area?
Establishment	• What is the best way to plant the seed? • Is different equipment required? • How easy is it to establish? • Will it create a solid cover? Good establishment is critical to the success of the cover crop.
Nutrient management	• Is it a nitrogen producer or does the cover crop require nitrogen to grow well? • Does it scavenge well for nitrogen?
Pest management	• What crop family is the cover crop in? • Is it related to other crops in the rotation? • Are there pest concerns?

Information on the most commonly used cover crops is provided below. See also Table 2-7, *Characteristics of Cover Crops Grown in Ontario*, on page 22.

Grass Crops

Grasses have fine, fibrous root systems that are well suited to holding soil in place and improving soil structure. Suitable grass species for cover crops are fast growing and relatively easy to kill, either chemically, mechanically or by winter weather. Grasses do not fix any nitrogen out of the atmosphere but can accumulate large quantities from the soil.

Ryegrass (Annual, Italian or Perennial)

Direct seed in spring or from August to mid-September, or seed with a nurse crop in spring. It has also been broadcast into corn in late June to early July with some success. Annual ryegrass gives the most top

COVER CROPS

Table 2-7.
Characteristics of Cover Crops Grown in Ontario

Species	Normal Seeding Time	Seeding Rate kg/ha[1]	Nitrogen Fixed[2]	Overwintering Characteristics	Potential Weed Problem From Volunteer Seed	Supports Nematodes[3]	
						Lesion	Root-knot
Grasses							
Ryegrass	April–May or August–early September	12–18	No	Annual, Italian partially survive; Perennial overwinters	No	—	—
Spring cereals	Mid-August–September	100–125	No	Killed by heavy frost	No	+	—
Sorghum sudan	June–August	50	No	Killed by frost	No	0	—
Pearl millet	June–August	4	No	Killed by frost	No	—	—
Winter wheat	September–October	100–130	No	Overwinters very well	No	+	—
Winter rye	September–October	100–125	No	Overwinters very well	No	+[4]	—
Legumes							
Hairy vetch	August	20–30	Yes	Overwinters	No	++	+
Red clover	March–April	8–10	Yes	Overwinters	No	++	+++
Sweet clover	March–April	8–10	Yes	Overwinters	No	—	—
Soybeans	August	40–50	Yes	Killed by frost	No	—	—
Field peas	August		Yes	Killed by heavy frost	No	—	—
Non-Legume Broadleaves							
Buckwheat	June through August	50–60	No	Killed by first frost	Yes	+++	0
Oilseed radish	Mid-August–early September	10–14	No	Killed by heavy frost	Yes	0	0

Nematode Rating Codes: — = poor or non-host + = ability to host 0 = some cultivars are non-hosts

[1] 100 kg/ha = 90 lb/ac

[2] Oilseed radish, buckwheat and the grasses do not fix nitrogen from the air but are scavengers of nitrogen from soil and manure applications.

[3] Varietal differences in cover crop species may affect nematode reaction.

[4] Rye: full season rating would be higher (+++)

growth in the seeding year, often heading 6–8 weeks after seeding. Italian ryegrass (a biennial) does not head in the seeding year, so top growth is considerably less. However, it has the largest, densest root system of the three types. Annual and Italian ryegrasses usually suffer considerable winterkill, but part of the stand may survive. Perennial ryegrass normally survives the winter.

Cautions: *Establishment and growth of ryegrasses can be poor during very hot, dry weather. It can be difficult to kill overwintering ryegrass with only cultivation or discing. The nitrogen tied up in ryegrass releases more slowly than from other cover crops. Thus corn after ryegrass often requires an extra 20–30 kg/ha (18–27 lb/ac) of nitrogen.*

Spring Cereals

Spring cereals are usually seeded for plowdown. Stands seeded from mid-August to mid-September will have 20-40 cm (8–16 in.) of growth by freeze-up. The stand is generally killed by late hard frosts.

Volunteer spring cereals are sometimes left to grow until freeze-up as a cover crop. Stands may not be very uniform. There may be up to 70 cm (28 in.) of growth by freeze-up, resulting in a heavy mat that keeps the soil wet the following spring. On erosion-prone knolls, spring cereals often have little growth and have been observed to "blow off" by spring, possibly opening the whole field to more erosion.

Cautions: *Early seeding may result in considerable growth by freeze-up. If left unplowed in the fall, the mat of dead residue will slow soil drying and warming in the spring, which can cause problems in early-seeded crops.*

Sorghum Sudan

Sorghum sudan is an excellent choice for growing as a green manure crop for soil improvement. The root growth is extensive and the top growth lush. A pre-plant herbicide treatment is recommended for crop establishment. Plant after all threat of frost has passed — mid-June. The crop will benefit from the warm temperatures of early to mid-summer. Approximately 50 kg/ha (45 lb/ac) of N will help the crop achieve maximum top growth.

Cautions: *Sorghum sudan should be mowed before it reaches a height of 1 m (3.28 ft), to encourage tillering and ensure that stalks are not woody and will break down readily.*

Pearl Millet

Pearl millet is a cover crop that has similar growth and other characteristics to sorghum sudan.

Winter Rye

Winter rye is seeded from September into mid-October. It grows until freeze-up, then commences growth again in late March–early April (slightly earlier than winter wheat). Growth rate is very rapid during May. The stand is generally killed in late April or early May by tillage or herbicide use.

Winter rye can be seeded later than any other crop and still survive over winter. For good ground cover and erosion protection, it should be seeded at least a month before freeze-up. Winter rye is one of the most consistent, flexible and economical cover crops available.

Cautions: *Rye will grow very rapidly under warm temperatures in early spring. Monitor growth to kill it at an appropriate time. It can deplete soil moisture, and incorporation can be difficult if it is allowed to grow too tall.*

Winter Wheat

Winter wheat can be seeded in late August through October. It can be seeded outside this time, however, similar to spring cereals, weather conditions may reduce top growth. Wheat will survive over winter and begin growing in April. The stand can be killed through tillage or herbicide application. The plant shuts down earlier in the fall and begins to grow later in the spring than rye.

Cautions: *Generally winter wheat does not provide the same amount of green material to return to the soil or the level of weed competition that rye provides.*

Legume Crops

Legume cover crops can fix nitrogen from the air, supplying nitrogen to the succeeding crop. Legumes also protect the soil from erosion and add organic matter. The amount of nitrogen fixed varies between species, although generally, more top growth equals more nitrogen fixed. Some legume species have aggressive tap roots that can break up subsoil compaction, but this requires more than one year's growth.

Nitrogen release from legumes can be inconsistent. This must be accounted for when calculating fertilizer needs.

Hairy Vetch

To provide good ground cover over the winter, hairy vetch must be seeded by mid-August. It grows slowly until freeze-up and establishes an extremely vigorous, fibrous root with moderate top growth. Hairy vetch may also be drilled into winter wheat when the wheat is about 20 cm (8 in.) tall. Seeding at this later stage prevents the hairy vetch from causing a problem with wheat harvest, but results in much more vetch growth by freeze-up than does an August seeding.

The vines resume growth early in the spring (similar time to winter wheat) and may reach 150 cm (60 in.) in length if left to maturity. Plowdown stands are usually killed in the spring by tillage or herbicide application. Vetch's fibrous root system improves soil structure, and large amounts of fresh organic matter are added to the soil.

Cautions: *Competition from volunteer cereals can lead to poor stands of hairy vetch. On droughty soils, hairy vetch left alive until early May can deplete soil moisture. Glyphosate is not effective in killing hairy vetch.* ***If hormone-sensitive crops are following, apply hormone sprays in the fall to avoid injury.***

Red Clover

Red clover is commonly broadcast into winter wheat in March or early April or seeded with spring cereals. Early seeding gives best stands. Double-cut red clover produces considerably more top growth than single cut (60 cm versus 25 cm, respectively). For plowdown, common seed produces equal results to pedigreed seed, although it may contain more weed seeds.

COVER CROPS

Major growth takes place from grain harvest until a heavy frost. Red clover can be killed in the fall or the spring by tillage or herbicide application. Unless herbicides are also applied, chisel plowing will not kill the stand completely.

Red clover plowdown improves soil structure and adds large amounts of fresh organic matter. Nitrogen is fixed and released slowly to the following crop. It gives excellent erosion protection when left unplowed until spring or killed in the fall with a herbicide.

Cautions: *Glyphosate alone is often not effective in killing red clover. If hormone-sensitive crops are following, apply hormone sprays in the fall to avoid injury.*

Sweet Clover

Sweet clover is most commonly seeded into winter wheat in March or early April or seeded with spring cereals. Either the yellow- or white-blossom type may be used. The white-blossom type produces somewhat taller top growth. Major growth takes place after the grain is harvested until heavy frost. Top growth will usually be 30–40 cm (12–16 in.) tall, but not dense. A strong taproot is produced, often 30 cm long and 1 cm across at the crown. If allowed to grow the following spring, sweet clover will flower in July at a height of about 180 cm (72 in.), set seed and die. Plowdown stands may be killed in the fall or the following spring by tillage or with herbicides.

Cautions: *Sweet clover is very sensitive to many herbicides and will not tolerate any phenoxy herbicides.*

Soybeans

Soybeans can be drilled in following spring or winter cereal harvest. With adequate moisture they will produce 20–40 cm (8–16 in.) of top growth before being killed by frost. Inoculation should not be necessary unless the soybeans are being grown in virgin ground.

Cautions: *Soybeans need more moisture to germinate than small seeded crops, so results may be disappointing in dry years. Since soybeans are a warm season crop, growth will slow or stop as the weather cools in the fall.*

Field Peas

Field peas will produce 60–90 cm (24–36 in.) of top growth before frost if drilled in following cereal harvest. They are adapted to cool, damp conditions, so will grow vigorously until well into the fall. The main drawback to field peas as a cover crop is the volume and cost of seed required.

Cautions: *A heavy mat of residue from a vigorous stand of field peas may delay soil drying in the spring, delaying tillage or planting.*

Non-Legume Broadleaf Crops

These broadleaf crops cannot fix nitrogen out of the air but may absorb large quantities from the soil. Neither of these crops is winter-hardy, so additional control measures are not normally required. They should not be allowed to go to seed, as the volunteer seed can become a significant weed problem.

Buckwheat

As a cover crop, buckwheat is most commonly seeded in late June–early August. It grows very rapidly, reaching the flower stage and a height of 45–75 cm (18–30 in.) in about 6 weeks. It has a relatively small fibrous root system and is completely killed by the first frost.

Buckwheat provides rapid soil cover, gives good erosion protection during the growing season, smothers annual weeds and suppresses perennial ones. Moderate amounts of fresh organic matter are returned to the soil. Buckwheat does not fix nitrogen.

Cautions: *Late summer seedings may be killed by an early frost before providing significant growth.*

Oilseed Radish

Oilseed radish is commonly seeded in August or very early September. It is unaffected by early frosts and can grow to a height of 50–90 cm (20–36 in.) and bloom in October. The plant has a thick but short taproot, varying between carrot- and turnip-shaped. It is killed by severe frosts in late November or December. It gives a reasonably rapid soil cover and excellent erosion protection over winter and returns moderate amounts of organic matter to the soil. For good growth, this crop must have a large amount of available nitrogen, either from a recent manure application or from nitrogen left from a previous crop.

Cautions: *Growth will be poor if soil nitrogen levels are low. Scattered volunteer plants usually appear in subsequent crops.*

Tillage Systems After Cover Crops

Cover crops reduce soil erosion potential by keeping the ground covered between crops, by improving soil structure and, in conservation tillage systems, by increasing surface residue cover.

Management factors to consider when reduced tillage follows cover crops are:

- Some regrowth of winter annual, biennial or perennial cover crops will occur in the following crop year. Usually this is easily controlled with normal herbicide treatments in the following crop. A controlled amount of regrowth can provide some spring wind protection.
- The first mulch tillage operation with overwintering cover crops should occur at least 2 weeks prior to planting to allow the breakdown of the residue to start.
- It may be difficult to prepare a seedbed if persistent cover crops are not tilled until spring and are allowed to grow too large.
- Cover crops that do not survive over winter may be an option, especially on more poorly drained soils or for crops that are planted very early in the spring.
- Burn-down herbicides should be considered before mulch tillage of overwintering cover crops such as rye. Careful timing and application of herbicides can help to keep enough residue on the surface to prevent wind damage to tender crops while allowing crop establishment.

Soil Compaction

Compaction is defined as increased bulk density and reduction in soil pore space. This occurs when the soil particles are forced closer together by the impact of equipment, animals and raindrops. The use of heavier tractors, combines and implements, particularly with earlier spring tillage, can cause problems under any tillage system.

Soils having high organic matter contents, good internal drainage and good structure are less susceptible to compaction. For further information, see the OMAFRA Factsheet, *Soil Compaction*, Order No. 88-082.

Detecting Compaction

Soil compaction can be detected easily with inexpensive tools.

- Identify the areas that have potential compaction problems.
- Using a tile probe or flexible rod, probe the affected area to a depth of 50 cm (20 in.) and compare to a fencerow or unaffected area.
- Insert the probe into the ground at a slow steady speed.
  - Your arms should be slightly bent, acting as the pressure gauge, measuring the force required to push the tip of the probe through the soil.
  - Note the depths at which the tip of the probe requires more force to push it through the ground. These areas may be where roots cannot penetrate.
- Use a shovel to dig up the plants in the affected area and examine the roots. Compare the roots to healthy plants from an unaffected area. The compacted area will have plants with malformed/restricted roots. Roots may be concentrated in the top few inches of the soil.

Note: When using a probe to compare compaction in different parts of fields, the areas measured must have similar moisture content for the results to be comparable.

Preventing Compaction

There are a number of management options to help prevent soil compaction.

- Keep off the field when the soil is wet, particularly with heavy equipment. The carrying capacity of dry soil is much greater than that of moist soil.
- Ensure tillage operations are performed when the soil is at proper moisture conditions at tillage depth.
- Install tile drainage in fields with variable or poor drainage.
- Use longer crop rotations that include forages/cereals.
- Leave forage crops in for more than 1 year.
- Alternate tillage depth so that tillage pans are not created.
- Minimize the amount of traffic on a field.
- Use radials, large tires or tracks that create a long narrow footprint to restrict compaction.
- Reduce the tire pressure to reduce the force on the surface of the soil. This will only be effective with radial tires and with large enough tires to carry the equipment at the reduced pressures. Check with the manufacturer that the tires are rated to operate at low pressures.
- Avoid high axle loading, which will cause compaction in the subsoil, even with low tire pressure. Keep equipment weight and loads as low as practical (below 4.5 tonnes/axle or 5 tons/axle). As often as possible, limit traffic with heavy equipment to laneways rather than tracking the entire field.

Subsoiling

Subsoiling is often used to try to loosen compacted areas of fields where heavy loads have passed. Harvest of some crops results in severely compacted areas that require this measure. Generally, subsoiling does not have a long-term effect. Always check for the presence of compaction using a tile probe or soil pit and check the moisture at depth before subsoiling. Deep tillage where the soil is not compacted will not provide any benefit and may damage soil structure below the normal depth of tillage.

Soil management, harvesting and manure application practices must change to avoid further problems. These changes include using lighter loads and staying off the soil when it is wet below the surface.

Drainage

Good drainage is essential for all farm operations. It will increase the yield of most crops and improve the efficiency of the overall operation.

Tile Drainage

Tile drainage artificially removes excess water from soil. It will actually increase the amount of available water in the soil by allowing crop roots to use a larger volume of soil.

Drainage is also an important conservation practice. It can reduce surface runoff by allowing more water to soak into the soil.

Surface Drainage

Surface drainage is often used to remove water from relatively flat areas of fields. While this serves to remove water from parts of a field, it can also contribute to soil erosion and the movement of nutrients into surface water.

Water Table Management

Traditionally, tile drains were installed simply to remove excess water from soil. However, recently, research shows these drains may serve a dual purpose: removing excess water and supplying water to the growing crop. By controlling water flow in the drains, groundwater levels are maintained near the bottom of the crop root zone. The consistent moisture source reduces stress and improves crop production. Controlling the amount of water that leaves the tiles also leads to more efficient use of nutrients and chemicals.

Erosion Control

The amount of soil lost from a field can be controlled or reduced by a number of the measures already mentioned in this chapter. Tillage erosion can only be reduced by minimizing the amount of tillage used. Minimum till, no-till, improved drainage and crop rotation, including cover crops, can go a long way to reducing wind and water erosion. In some situations, these measures are not enough, and other soil conservation practices become necessary. Table 2-8, *Water Erosion Control*, on page 27, lists a number of erosion control structures and their uses.

Water Erosion Control

A number of structures can be used to control a concentrated flow that is causing a gully or rill in a field (see Table 2-8, *Water Erosion Control*, on page 27). These structures will require less maintenance if combined with minimum till or no-till. Strip cropping is another option for protecting the soil from water erosion. This practice involves planting alternating strips of row crops with a cereal or forage. Combining conservation tillage with strip cropping will increase the width of the strips required.

Stream and Ditch Protection

Ditch and stream banks are often a significant source of sediment in water. Unprotected banks will continue to erode, cutting into valuable farmland. Increasing calls to protect ground and surface water underline the need to protect this resource. A number of measures can be implemented to protect stream and ditch banks as well the water flowing in them. High stream flows, cattle and machinery can subject banks to erosion. Concentrated flows entering a watercourse can cause rill or gully erosion. Stream banks and ditches are usually stabilized with one or more of the following: drop pipes, rock chutes, buffer strips, tile outlet protection or header tile.

Livestock should be restricted from all watercourses; many fencing options are available. Bridges, culverts or low-level crossings are some of the options available to move livestock and machinery safely.

Windbreaks and Shelterbelts

Often additional protection from the wind is necessary when there is not enough residue to hold soil in place. Windbreaks and shelterbelts can provide that protection by slowing down wind speeds near the ground. Windbreaks usually have five or fewer rows and shelterbelts have six or more rows.

Fragile Land Retirement

Occasionally, the erosion cannot be controlled on a field or part of a field. The erosion may be too extreme or the field has some other limitation making it unprofitable or unsustainable to farm. Fragile land could include areas along creeks, lakes and wetlands that may be subject to flooding or

Table 2-8.
Water Erosion Control

Erosion Control Practice	Description	Use	Comments
Water and sediment control basin	• structure is built across drainage ways • works like a small dam • intercepts concentrated runoff and takes it underground through a tile	• to protect against rill and gully erosion through a field or farm • useful in fields with irregular and non-uniform slopes • can be used instead of grass waterways	• relatively inexpensive to install
Grass waterways	• broad, shallow channels • a grass cover protects it from erosion	• to protect against rill and gully erosion through a field or farm • can act as an outlet for terraces, diversions, contour rows or to carry water entering the field from neighbouring fields	• equipment can easily cross waterway • crop rows should be at right angles to the waterway
Diversion terrace	• diversion channel with a ridge on the lower side	• constructed across a slope to intercept surface runoff carrying it to an outlet	
Terraces	• constructed across the slope • used to break up long slopes • excess water is carried safely off the field • the three common types are broad base, grass backslope and narrow base	• to protect against gully, rill and sheet erosion	• most expensive erosion control structure • terrace spacing is based on steepness of slope, soil erodibility, crop type, management and rainfall
Strip cropping			
1. Contour strip cropping	• strips are planted at right angles to the natural slope of the land	• to protect against sheet and rill erosion	• technical assistance may be required to set up contours • can reduce erosion by up to 75%
2. Field strip cropping	• strips of uniform width are planted across the slope	• to protect against sheet and rill erosion	• most common form of strip cropping • can reduce erosion by up to 75%
3. Contour buffer strip cropping	• permanent strips of grass or forage are planted between even-width strips of crops in regular rotation	• to protect against sheet and rill erosion	• the width of the strips are based on the crop rotation and severity of the slope

other land that is subject to severe erosion. This land should be retired from production to pasture or woods.

Water Quality

Water is a valuable resource. A clean and abundant supply of water is critical to the success of a farm business and the health of the family. Others, including fish and wildlife, also share the water. It is a privilege to expect an ample supply of clean water and a responsibility to make sure the water leaving the farm is abundant and clean for the next user.

Farm operations impact water quality in many ways. Soil erosion, manure, septic system effluent, milkhouse wastes, pesticides and fuels can affect surface water quality. Nutrients, manure, pesticides and fuels moving down through the soil can affect groundwater quality.

The greatest water quality challenges affecting producers involve bacteria (from manure), nitrates and sediment. Pesticide contamination is much less of a problem. The following problems can be minimized using the practices listed.

Bacterial Contamination

- Contain runoff from manure storages, livestock yards and silos.
- Avoid spreading manure on frozen or snow-covered ground.
- Ensure that the water well is properly maintained and protected from surface contamination.

- Properly treat or store milkhouse waste water.
- Ensure that the domestic septic system is working properly and is not discharging into a drainage system.

Soil Erosion

- Adopt conservation tillage practices as outlined earlier in this section.
- Install erosion-control structures.

Nitrate Contamination

- Complete a nutrient-management plan for the farm.
- Avoid spreading excessive amounts of manure or fertilizer on a field.
- Where a lot of manure and forages are used, the nitrate soil test can help to determine nitrogen requirements.
- Reduce nitrogen fertilizer when the previous crop was a legume or when manure was applied (see the section *Adjustments to Fertilizer Recommendations,* on page 36).

Pesticide Contamination

- Store pesticides properly and keep as little as possible in storage.
- Stay away from ditches and other sources of water when spraying.
- Clean up spills quickly and thoroughly.
- Be careful not to mix up more pesticide than you need.

Fuel Contamination

- Store fuel away from wells, ditches, etc.
- Use automatic shut-off nozzles to prevent spills.

The following OMAFRA/Agriculture and Agri-Food Canada/ Ontario Federation of Agriculture booklets contain more information on water quality problems and solutions, soil conservation measures and nutrient and manure use.

- *Best Management Practices — Water Management*
- *Best Management Practices — Field Crop Production*
- *Best Management Practices — Nutrient Management*
- *Best Management Practices — Pesticide Storage, Handling and Application*
- *Best Management Practices — Water Wells*

For more information on soil testing and fertilizer use, refer to OMAFRA Publication 611, *Soil Fertility Handbook.*

Soil Testing

Ontario currently uses about 690,000 tonnes (760,000 tons) of fertilizers annually. High yields can be produced efficiently only when fertilizer use is related to the fertility level of the soil and to other additions of nutrients from manure, crop residues and other organic sources. At one extreme, on very low fertility soils, it is occasionally profitable to add as much or more nitrogen, phosphorus or potassium in the fertilizer as a crop removes. At the other extreme, on high fertility soils or following heavy application of manures, fertilizer may not be profitable and occasionally may reduce yields.

Why Soil Test?

The OMAFRA-accredited soil tests are the most accurate tool available to Ontario growers to determine the amounts of phosphorus, potassium and magnesium fertilizers and lime that should be applied for crop production. Ask for the OMAFRA-accredited soil tests.

Other Methods of Assessing Nutrient Needs

1. Plant analysis is the main tool used for tree fruits and can provide additional information to support the soil test for field and vegetable crops.
2. Nutrient deficiency symptoms on crop leaves are helpful in evaluating nutrient deficiencies in some cases. However, they have serious drawbacks in others, particularly with potassium and phosphorus, because serious yield losses occur before symptoms are visible.
3. It is occasionally suggested that a grower apply the amounts of nutrients removed by the crop. This has some application for nitrogen, as with some crops, the suggested rate approximates what the plant removes. It has little relevance for other nutrients in Ontario. Some of our clay and clay loam soils have sufficient potassium to last many years, and application of potassium each year on those soils is a waste of money and ignores one of the few advantages that clay soils have over coarser-textured soils.

The OMAFRA-accredited soil testing program is the main guide, along with help from plant analysis and nutrient deficiency symptoms in determining the fertilizer requirements for a specific crop on a specific field.

The OMAFRA-Accredited Soil-Testing Program

The OMAFRA-accredited soil testing program provides assurance of appropriate analyses to support recommendations for nitrogen, phosphate, potash and magnesium fertilizer, along with recommenda-

Table 2-9. OMAFRA-Accredited Soil Tests

Materials Analyzed	What Is Analzyed[1]
Soils for field crops, commercial turf, etc.	Plant-available phosphorus (sodium bicarbonate extractable); potassium, magnesium (ammonium acetate extractable), manganese and zinc (index of soil pH and extractable element); pH; lime requirement (SMP buffer pH)

[1] Soil organic matter can be useful for herbicide recommendations but is not an accredited test.

tions for the amount and type of lime that should be applied. The analytical methods used were chosen to provide accurate results on the range of soils found in Ontario. Table 2-9, *OMAFRA-Accredited Soil Tests*, above, lists the tests provided on an accredited soil test in Ontario.

Nitrate nitrogen can be measured on a separate, deeper sample. See the section *Nitrogen*, on page 64, for further information.

Soil test results for phosphorus, potassium and magnesium are reported in units of milligrams per litre of soil (mg/L), which is approximately equal to parts per million. Plant-available phosphorus is measured with a sodium bicarbonate extract (also known as the Olsen extract). Plant-available potassium and magnesium are measured with an ammonium acetate extract. Manganese and zinc are reported as indexes that account for both the amount of nutrient extracted from the soil, and the soil pH. Soil pH has a huge impact on the amount of these nutrients that is available to plants.

These analyses have been found to be the most accurate estimates of plant-available nutrients for soils in Ontario.

The OMAFRA-recommended fertilizer rates are provided in this publication. They are designed to produce the highest economic yields when accompanied by good or above-average management. Research shows that higher rates will occasionally produce higher yields but that these increases in yield are likely to be small and not profitable. Some fertilizer is recommended at soil test levels slightly above those where crop response is profitable. This is done to maintain high soil nutrient levels and to allow for some error in sampling the field. For high-value crops such as tobacco, the maximum profit we aim for will require essentially the same amount of fertilizer as maximum crop value (maximum yield with high quality). For low-value crops, there may on occasion be a slight yield response to rates of fertilizer above those recommended for maximum profit. However, trials on farm fields with corn have shown no yield response to rates of fertilizer above those recommended by soil test. For further assistance in interpreting soil test reports, contact a Certified Crop Advisor or call the OMAFRA Agricultural Information Contact Centre (1-877-424-1300).

See Appendix B, *Accredited Soil-Testing Laboratories in Ontario*, on page 257, for a list of accredited labs in Ontario.

Soil Tests From Other Laboratories

Each year a number of growers ask OMAFRA staff to interpret results from laboratories that are not accredited. Provided the other laboratory uses the identical test used by the OMAFRA-accredited service and expresses its test results in the same units, the OMAFRA fertilizer requirements for phosphate and potash can be determined, but there is no assurance how accurate the analyses are.

Only OMAFRA-accredited soil tests can be relied on to provide accurate fertilizer recommendations. Be certain that the service you are using is accredited. To be accredited, a laboratory must use OMAFRA-approved testing procedures, must demonstrate acceptable analytical precision and accuracy and provide the OMAFRA fertilizer recommendations.

A number of laboratories provide soil tests such as exchange capacity, aluminum, boron and copper not accredited by OMAFRA. These are not accredited by OMAFRA because they have not been found to contribute to better fertilizer recommendations. Research has shown that on Ontario soils, use of exchange capacity to adjust potash recommendations can lead to less reliable recommendations than are now provided.

Soil Sampling

Soils may be sampled with a sampling tube or with a shovel. Each field or uniform section of a field should be sampled separately. At least 20 soil cores, 15 cm (6 in.) deep should be taken from any field or area sampled up to 5 ha in size. For fields larger than 5 ha (12.5 ac), proportionately more cores should be taken. See Figure 1-1, *Scouting Patterns*, on page 2, for appropriate sampling patterns for soil sampling. The more cores taken, the more likely the soil sample is to provide a reliable measure of the fertility in the field. One sample should not represent more than 10 ha (25 ac).

The soil can be collected in a clean plastic pail, the lumps should be broken, the soil mixed well and a soil sample box forwarded for testing. The area sampled should be traversed in a zigzag pattern to provide a uniform distribution of sampling sites. Parts of a field that differ in appearance of soil or crop, in previous fertilization, manuring or liming should be sampled separately, even if they are too small to fertilize separately. Avoid sampling recent fertilizer bands, dead furrows, areas adjacent to gravel roads or where lime, manure, compost or crop residues have been piled.

When to Sample

Each field should be sampled once every 2 or 3 years. Potash levels can change quickly where large amounts of nutrients are removed from sandy soils (for example, with crops such as alfalfa hay, corn silage, potatoes or tomatoes). Under these conditions, samples should be taken each year.

To allow time for mailing and analysis, soil samples from fields to be fertilized for spring seeding crops should be taken the previous fall. Because of the rush of harvest and the frequency of poor weather late in the fall, summer may be a more convenient time to sample for some growers.

Sample Boxes and Information Sheets

Soil sample boxes, information sheets and information on the cost of various tests may be obtained from any of the accredited labs, or from many fertilizer and farm supply outlets.

Management practices that affect a soil test recommendation are manure application, legume sod plowed down and the crop to be fertilized. This information is essential for a reliable fertilizer recommendation and should be recorded on the field information sheet that must accompany the soil sample sent in for analysis.

Micronutrient Tests

OMAFRA-accredited tests are available for manganese and zinc. In the case of zinc on corn, the soil test is best used in conjunction with visual deficiency symptoms. With manganese, plant analysis, visual symptoms and the soil test are all useful. OMAFRA-accredited tests are not available for boron, copper, iron or molybdenum. The available tests for these nutrients have not provided good estimates of the availability of these nutrients to plants. Plant analysis is generally a better indicator of deficiencies of these nutrients.

Contamination

Great care is required to prevent contamination of soil samples with micronutrients, particularly zinc. Do not use galvanized (zinc-plated) soil sampling tubes to take soil samples for micronutrient tests. Do not use metal containers to collect and mix samples. Clean plastic containers in good condition should be satisfactory. Soil samples that have contacted galvanized surfaces are unsatisfactory for zinc soil tests. Be careful to keep dust around buildings, etc., out of the samples.

Soil Sampling

Micronutrient deficiencies frequently occur in small patches in fields. In these cases, soil or plant analysis taken from the entire field is unlikely to find the problem. Sample problem areas separately.

Plant Analysis

Plant analysis measures the nutrient content of plant tissue. Comparing the results against the "normal" and "critical" values for the crop can indicate whether nutrient supply is adequate for optimum growth.

Plant analysis is the basis of fertilizer recommendations for tree fruits and grapes and is a useful supplement to soil testing for evaluation of the fertility status of other crops. It is quite independent of soil testing and can provide a valuable "second opinion," especially for phosphorus, potassium, magnesium and manganese. For nitrogen and zinc, it has not been very reliable. For boron and copper there is not a reliable soil test, so plant analysis and visual symptoms are the methods used for diagnosing deficiencies.

Plant analysis has limitations. Interpreting the results is often difficult since plant analysis does not usually indicate the cause of a deficiency or the amount of fertilizer required to correct it. Plant analysis is most useful if combined with visual inspection of the crop and soil conditions, knowledge of past management in the field and a current soil test to provide information about soil nutrient levels and soil pH.

There is no formal accreditation process for plant tissue analysis. However, the performance of the accredited labs in plant tissue analysis is monitored, and any of the accredited soil test labs can do a good job of analyzing plant tissue samples.

Sampling

The time of sampling has a major effect on the results, since nutrient levels within a plant vary considerably with the age of the plant. Results are difficult to interpret if samples are taken at times other than those recommended. Nevertheless, plants suspected of being nutrient deficient should be sampled as soon as a problem appears. Samples are best taken from a

Table 2–10.
Soil pH at Which Lime Is Recommended for Ontario Crops

Crops	Soil pH Below Which Lime Is Recommended	Target Soil pH[1]
Coarse and medium-textured mineral soils (sand, sandy loams, loams and silt loams)		
Perennial legumes, oats, barley, wheat, triticale, beans, peas, canola, flax, tomatoes, raspberries, strawberries, all other crops not listed below	6.1	6.5
Corn, soybeans, rye, grass, hay, pasture, tobacco	5.6	6.0
Potatoes	5.1	5.5
Fine-textured mineral soils (clays and clay loams)		
Alfalfa, cole crops, rutabagas	6.1	6.5
Other perennial legumes, oats, barley, wheat, triticale, soybeans, beans, peas, canola, flax, tomatoes, raspberries, all other crops not listed above or below	5.6	6.0
Corn, rye, grass hay, pasture	5.1	5.5
Organic soils (peats and mucks)		
All field and vegetable crops	5.1	5.5

[1] Where a crop is grown in rotation with other crops requiring a higher pH (for example, corn in rotation with wheat or alfalfa), lime the soil to the higher pH.

problem area rather than from the entire field, and it is often helpful to sample an adjacent area of healthy plants at the same time, for comparison.

Samples for plant analysis should be taken from at least 20 plants distributed throughout the area chosen for sampling. Each sample should consist of at least 100 gm (3.5 oz) of fresh material. Problem areas should be sampled separately. When taking samples for plant analysis, take care not to contaminate the sample with soil. Even a small amount of soil will cause the results to be invalid, especially for micronutrients.

Sample Preparation

Samples of fresh plant material should be delivered directly to the laboratory. If they are not delivered immediately they should be dried to prevent spoilage. Samples may be dried in an oven at 65°C (149°F) or less or dried in the sun, provided precautions are taken to prevent contamination with dust or soil. Avoid contact of samples with galvanized (zinc coated) metal, brass or copper.

Fertilizer Recommendations

Soil Acidity and Liming

The pH scale ranging from 0 to 14 is used to indicate acidity and alkalinity. A pH value of 7.0 is neutral; values below 7.0 are acid and those above 7.0 are alkaline. Most field crops grow well in a soil pH range from 6.0 to 8.0.

Changes in Crop or Management

Fertilizer requirements on the OMAFRA soil test report are for specific crop and management. Adjustments in fertilizer requirements may be needed if changes are made in manure application or if legumes are going to be incorporated. For fertilizer adjustments, see Table 2–15, *Adjustment of Nitrogen Requirement Where Crops Containing Legumes Are Plowed Down*, on page 36. Changing the crop from the original soil test recommendation will require a new fertilizer recommendation. This can be obtained by looking up the appropriate table under the specific commodity chapter in this publication.

To correct soil acidity, ground limestone should be broadcast and worked into the soil at rates determined by soil test. Table 2–10, *Soil pH at Which Lime Is Recommended for Ontario Crops*, above, shows the pH values below which liming is recommended and the target soil pH to which soils should be limed, for different crops. In Ontario, most crops grow quite well at pH values higher than the target pH to which liming is recommended.

The Buffer pH

The soil pH measures the amount of acidity in the soil solution and indicates whether liming is necessary for crop production. It does not measure the amount of reserve acidity held on the clay and organic matter particles in the soil, which will dictate how much lime is needed. Different amounts of

Table 2–11.
Lime Requirements to Correct Soil Acidity Based on Soil pH and Soil Buffer pH[1]
Ground limestone required – tonne/ha
(based on Agricultural Index of 75)

Buffer pH	Target Soil pH			
	7.0	6.5[2]	6.0[3]	5.5[4]
7.0	2	2	1	1
6.9	3	2	1	1
6.8	3	2	1	1
6.7	4	2	2	1
6.6	5	3	2	1
6.5	6	3	2	1
6.4	7	4	3	2
6.3	8	5	3	2
6.2	10	6	4	2
6.1	11	7	5	2
6.0	13	9	6	3
5.9	14	10	7	4
5.8	16	12	8	4
5.7	18	13	9	5
5.6	20	15	11	6
5.5	20	17	12	8
5.4	20	19	14	9
5.3	20	20	15	10
5.2	20	20	17	11
5.1	20	20	19	13
5.0	20	20	20	15
4.9	20	20	20	16
4.8	20	20	20	18
4.7	20	20	20	20
4.6	20	20	20	20

[1] Buffer pH in Ontario is measured using the Shoemaker, MacLean and Pratt (SMP) buffer. Other jurisdictions may use different buffers, which will give similar but not identical results.

[2] Lime if soil pH below 6.1.

[3] Lime if soil pH below 5.6.

[4] Lime if soil pH below 5.1.

reserve acidity will mean that two soils at the same pH value will need different amounts of lime to raise the pH to the desired level. The reserve acidity is measured in a separate test: the buffer pH. The greater the amount of reserve acidity, the lower the buffer pH and the more lime is required to raise the pH. For soils needing lime (based on soil pH), Table 2–11, *Lime Requirements to Correct Soil Acidity Based on Soil pH and Soil Buffer pH*, above, may be used to determine the amount of lime required to reach different "target" soil pH values required for different crops.

Limestone Quality

Calcitic limestone consists largely of calcium carbonate, and dolomitic limestone is a mixture of both calcium and magnesium carbonates. Dolomitic limestone should be used on soils with a magnesium soil test of 100 or less, as it is an excellent and inexpensive source of magnesium for acid soils. On soils with magnesium tests greater than 100, calcitic or dolomitic limestone may be used.

The two main factors that affect the value of limestone for soil application are neutralizing value and particle size. Neutralizing value is the amount of acid a given quantity of limestone will neutralize when it is totally dissolved. It is expressed as a percentage of the neutralizing value of pure calcium carbonate. A limestone that will neutralize 90% as much acid as pure calcium carbonate is said to have a neutralizing value of 90. In general, the higher the calcium and magnesium content of a limestone, the higher the neutralizing value.

The second factor that affects the value of limestone as a neutralizer of acidity is the particle size. Limestone rock has much less surface area to react with acid soil than finely powdered limestone and, hence, it neutralizes acidity much more slowly; so slowly that it is of little value. The calculation of a fineness rating for ground limestone is illustrated in Table 2–12, *Example Calculation of the Fineness Rating of a Limestone*, on page 33.

The Agricultural Index

This index has been developed in Ontario as a means of combining the neutralizing value and the fineness rating to compare various limestones that are available.

$$\text{The Agricultural Index} = \frac{\text{neutralizing value} \times \text{fineness rating}}{100}$$

The Agricultural Index can be used to compare the relative value of different limestones for neutralization of soil acidity. Lime with a high Agricultural Index is worth proportionately more than lime with a low index because it may be applied at a lower rate.

For example, if two ground limestones, A and B, have Agricultural Indices of 50 and 80 respectively, the rate of application of limestone A required for a particular soil will be 80/50 x the rate required for limestone B. Limestone A spread on your farm is worth 50/80 x the price of limestone B per tonne.

**Table 2–12.
Example Calculation of the
Fineness Rating of a Limestone**

Particle Size	% of Sample		Effectiveness Factor		
Coarser than No. 10 sieve[1]	10	x	0	=	0
No. 10 to No. 60[2] sieve	40	x	0.4	=	16
Passing through No. 60 sieve	50	x	1.0	=	50
Fineness Rating				=	66

[1] A #10 Tyler sieve has wires spaced 2.0 mm apart.
[2] A #60 Tyler sieve has wires spaced 0.25 mm apart.

Recommendations from the OMAFRA soil test service are based on limestone with an Agricultural Index of 75. If the Agricultural Index is known, a rate of application specifically for limestone of that quality can be calculated. This can be done using the following equation:

$$\text{Limestone application rate from soil test} \times \frac{75}{\text{Agricultural Index of limestone}} = \text{Rate of application of limestone}$$

For example, if there is a limestone requirement by soil test of 9 t/ha, and the most suitable source of limestone from a quality and price standpoint has an Agricultural Index of 90, then 7.5 t/ha (75/90 x 9) should be applied.

The Agricultural Index does not provide information about magnesium content. Dolomitic limestone should be used on soils low in magnesium.

Tillage Depth

Lime recommendations presented here should raise the pH of the top 15 cm (6 in.) of a soil to the listed target pH. If the soil is plowed to a lesser or greater depth than 15 cm, proportionately more or less lime is required to reach the same target pH. Where reduced tillage depths are used, rates of application should be reduced proportionately. More frequent liming will be needed.

Lowering Soil pH

On soils with pH values below 6.5, it is possible to lower the pH (make the soil more acid) by adding sulphur or ammonium sulphate. This may be desirable for some crops, for example, potatoes for scab control, but usually will not be suitable for rotation crops. Soil pH can not be adjusted from a low pH to a more moderate pH year to year. If the soil pH is above 6.5, it is not advisable and also usually quite impractical to lower the soil pH because of the very large amounts of sulphur or ammonium sulphate required.

Nitrogen

Nitrogen fertilizer recommendations for field crops are based on estimated crop requirements. Recommended rates are presented in tables found in the *Fertilizer* section for each crop chapter. Rates are adjusted downward if manure is applied, or if the previous crop contains perennial legumes such as alfalfa.

To protect crop quality and avoid movement of nitrogen into the groundwater, the combined application of fertilizer, manure, biosolids and residuals and other sources of nitrogen should not supply plant-available nitrogen in excess of the crop's requirement.

Phosphate and Potash

Phosphate and potash recommendations are based on OMAFRA-accredited soil tests. The requirements of these nutrients are presented in the *Fertilizer* section for each crop chapter. These tables should be used only with OMAFRA-accredited soil tests. Non-accredited tests may use extractants that pull out different amounts of nutrient so they will not give correct answers if used with the OMAFRA tables.

Where a soil test is not available, a rough estimate of requirements can be obtained from these tables using the following guidelines:

- Where the field has been fertilized regularly for a number of years or heavily in recent years, use one of the rates of phosphate and potash recommended for the *MEDIUM* soil test rating.
- If the field has received little fertilizer in the past, use one of the rates recommended for a *LOW* soil test rating.

Soils testing excessive (E) for phosphorus contain much more plant-available phosphorus than is required by most crops. Application of additional phosphorus, whether from fertilizer, compost, manure or sewage biosolids and residuals, is unlikely to provide a yield increase and may interfere with the availability of other nutrients.

The rating system for soil test phosphorus evaluates the likelihood of a crop response to applied phosphorus. The risk of surface water contamination by phosphorus may be increased at higher soil test phosphorus levels. However, since phosphorus binds tightly to soil particles, the movement of soil off the field through erosion is also a major factor in determining the risk of surface water contamination. It is for this reason that the risk of surface water contamination by phosphorus cannot be based solely on a soil test phosphorus level. Wherever soil tests are very high or excessive, applications of any source of phosphorus should be guided by a Phosphorus Index (refer to Appendix C, *Phosphorus Index*, on page 258). A Phosphorus Index can rank the relative risk of surface water contamination for applications made to a particular area of land. It will also determine maximum application rates, if manure is applied, and required setbacks from watercourses.

Some clay and clay loam soils are naturally high in potassium and do not require any potash fertilizers. Only a soil test can adequately determine potash requirements.

Magnesium

Magnesium is a nutrient that is naturally plentiful in many Ontario soils. Soils with magnesium soil tests below 20, according to an OMAFRA soil test, require magnesium application for production of most crops. Very few Ontario soils have magnesium test results below 20. If the soil pH is below 6.0, the most effective and inexpensive means of supplying magnesium is by application of dolomitic lime. Use dolomitic lime to correct soil pH if the magnesium soil test is below 100. On soils with a higher magnesium test, either dolomitic or calcitic lime can be used to correct soil pH. If the pH is above 6.0, and the soil test result is 20 or below, magnesium can be supplied by either magnesium sulfate or sulfate of potash magnesia (a mixture of sulfate of potash and magnesium sulfate). Apply 30 kg/ha (27 lb/ac) of actual soluble magnesium. These latter sources of magnesium are usually quite expensive compared to supplying magnesium from dolomitic limestone.

Potassium competes with magnesium for uptake by crops, and potash applications can therefore induce or increase magnesium deficiency. For this reason, it is important to monitor soil potassium levels and carefully control potash fertilizer applications on low magnesium soils.

Crops grown on a number of Ontario soils are low in magnesium to an extent that livestock health is affected, although the crops themselves do not suffer from magnesium deficiency. In these situations, it is usually much less costly to add magnesium to the animal's diet than to add it to the soil. Soil potassium should be closely monitored, however, and potash applications restricted to requirements as measured by soil test.

Calcium

Calcium deficiency has not been a problem on Ontario soils with soil pH adequate for field crop growth. Adequate soil pH is a reliable indicator of adequate calcium in the soil.

Sulphur

Sulphur is generally provided in adequate amounts for crop growth in acid precipitation and from organic matter breakdown. There have been reports of sulphur deficiencies from a few fields in northwestern Ontario, mainly on sandy soils with low organic matter. Where sulphur is required, it can be applied as either ammonium sulphate or potassium sulphate. Elemental sulphur can be used, but it must be oxidized to the sulphate form before the plants can absorb it. It therefore needs to be applied 12–18 months before a crop requiring sulphur is planted.

Micronutrient Fertilizers

Micronutrient elements should not be combined with insecticide or fungicide sprays unless the manufacturer's directions indicate that this may be done.

Micronutrient elements should be applied only on competent advice or where experience has proven their application to be necessary. Soil or foliar applications can be made. Soil applications are generally made at soil-preparation time, and foliar applications are applied during the growing season. A sticker spreader should be included in micronutrient sprays.

Manganese

Preventing and Correcting Manganese Deficiency

The general symptom of manganese deficiency is interveinal chlorosis of leaves, which begins on the younger foliage. Later, the whole plant may be affected. Cereals show manganese deficiency as a general yellowing and stunting, occasionally with grey specks on the leaves. The crops most susceptible to manganese deficiency are soybeans, edible beans and cereals.

Manganese is less available at high soil pH, so it is important not to add more lime than is needed to correct soil acidity. For materials and rates to correct a deficiency, consult the sections *Micronutrients*, on page 110 and page 190. Interpretation of the manganese soil test is found in Table 2–13, *Manganese Soil Test Interpretation*, on page 35.

Zinc

Preventing and Correcting Zinc Deficiency

Corn is the main crop showing zinc deficiency in Ontario. Zinc deficiency has been reported in beans in other areas but it appears to be rare in

Table 2-13.
Manganese Soil Test Interpretation

Managanese Soil Test[1]	Suggested Treatments
greater than 30	Soil manganese availability is adequate for field-grown crops.
16 to 30	Soil manganese availability is adequate for many crops but is approaching deficiency levels for oats, barley, wheat and soybeans. If deficiency symptoms appear, spray with manganese. Consider a recheck for deficiency using plant analysis.
below 16	Soil manganese availability is believed to be insufficient for oats, barley, wheat and soybeans. Spray with manganese at the four-leaf stage and again 3 weeks later if required. Manganese deficiency has not been diagnosed on corn in Ontario, even on soils that are very deficient for wheat.

[1] These values are indices of manganese availability based on extractable soil manganese and soil pH.

Table 2-14.
Zinc Soil Test Interpretation

Zinc Soil Test[1]	Suggested Treatments
greater than 200	Suspect contamination of the sample or of the field.
25 to 200	Soil zinc availability is adequate for most field-grown crops.
15 to 25	Zinc availability is adequate for most field crops but is bordering on deficiency for corn. If the field sampled is uneven in soil texture, pH or erosion, some areas may respond to zinc applications. Deficiency symptoms at the four- to six-leaf stage are a reliable indication of zinc deficiency (see the section *Zinc*, on page 69).
less than 15	Zinc is likely to be deficient for corn and should be applied in the fertilizer.

[1] These values are indices of zinc availability based on extractable soil zinc and soil pH.

Ontario. High phosphorus in the soil and/or in the fertilizer can cause or increase the severity of zinc deficiency. **Apply only the recommended amount of phosphorus**. Use of animal manures can prevent or reduce zinc deficiency. Erosion control can prevent deficiency of zinc by maintaining the topsoil.

Zinc deficiency can be prevented by application of zinc fertilizer to the soil at a rate of 4 kg/ha (3.6 lb/ac). Up to 14 kg/ha (12.5 lb/ac) can be broadcast, and this will correct a deficiency for 3 years, but not more than 4 kg/ha (3.6 lb/ac) should be banded. Foliar sprays can be useful to correct a deficiency after the symptoms have appeared provided this is done early in the growing season. For further details on materials and rates to correct a deficiency, consult the section *Secondary and Micronutrients*, on page 69, in the corn chapter. Interpretation of the zinc soil test is found in Table 2-14, *Zinc Soil Test Interpretation*, right.

Copper

Copper soil tests are quite unreliable on Ontario soils but plant analysis is useful. Copper is unlikely to be deficient on mineral soil, except perhaps on very sandy soils. Copper deficiency does occur on organic soils and is best diagnosed by plant analysis. When organic soils are first brought into cultivation, copper should be applied to the soil at 14 kg/ha (12.5 lb/ac) for each of the first 3 years.

Boron

Boron is required on some soils for alfalfa, particularly on sandy or gravelly soils with low water-holding capacity. Deficiencies are more common in central Ontario than in the rest of the province. Boron deficiency occurs most frequently during dry weather and the response to boron may be inconsistent. Thus it has not been possible to develop a reliable soil test. Plant analysis is useful as a predictor of boron requirements as are visual symptoms on the plants. For rates of boron to correct a deficiency, consult the section *Micronutrients*, on page 150.

Because boron is needed only in very small quantities, and since an overdose is toxic, extreme care should be taken in its use. Boron deficiency has not been diagnosed in cereals, peas and beans in Ontario, and boron applications to these crops, or applied to other crops in the year preceding them, can be toxic. **Boron should not be banded.**

Iron and molybdenum have not been found to be deficient in field crops in Ontario.

Table 2-15.
Adjustment of Nitrogen Requirement Where Crops Containing Legumes Are Plowed Down

Type of Crop	For All Crops, Deduct From N Requirement kg/ha	For All Crops, Deduct From N Requirement lb/ac
Less than 1/3 legume	0	0
1/3 to 1/2 legume	55	49
1/2 or more legume	100	89
Perennial legumes seeded and plowed in the same year	45[1]	40[1]
Soybean and field bean residue	0[2]	0[2]

[1] Applies where the legume stand is thick and over 40 cm (16 in.) high.

[2] For all crops other than corn. For adjustments to corn fertilizer requirements, see Table 3-19, *General Recommended Nitrogen Rates for Corn,* on page 67.

Adjustments to Fertilizer Recommendations

The general fertilizer recommendations in this book apply to situations where no organic sources of nutrients have been applied to the field. If manure or biosolids are applied to the land, or if legumes are plowed down, fertilizer rates should be reduced to adjust for the nutrients applied in the organic form.

Adjustment for Legumes Plowed Down

When sod containing perennial legumes such as alfalfa, birdsfoot trefoil and clover are plowed under, they supply an appreciable amount of nitrogen to the following crop. Table 2-15, *Adjustment of Nitrogen Requirement Where Crops Containing Legumes Are Plowed Down,* above, shows reductions that should be made in nitrogen fertilizer applications to crops following sod containing legumes.

Adjustments for Manure Application

A large number of Ontario farms produce livestock, generating over 33 million tonnes of manure. Proper management of the nutrients from manure is essential for optimum economic benefit to the farmer with minimal impacts on the environment.

The Value of Manure

The value of manure in crop production is often under-estimated. Manure contains all of the nutrients needed by crops but not necessarily in the proportions needed for specific soil and crop conditions. In addition to nitrogen, phosphorus and potash, manure contains many secondary nutrients and micronutrients as well as organic matter that help build and maintain soil structure.

An Example

A farmer spreads 45,000 L of liquid finisher swine manure per hectare (4,000 gal per acre) in the spring, working the manure into the soil within 24 hours.

Fertilizer	Equivalent Amount		Price/kg[1]		Cost/ha
Nitrogen	153 kg/ha	x	0.88	=	$134.64
P_2O_5	66 kg/ha	x	0.77	=	$50.82
K_2O	96 kg/ha	x	0.38	=	$36.48
Total value per hectare				=	$221.94

[1] Price based on average commercial fertilizer costs in 2001.

The equivalent amount of commercial fertilizer can be calculated using Table 2–16, *Average Amounts of Dry Matter, Nitrogen and Available Phosphate and Potash for Different Types of Organic Nutrient Sources,* on page 37, and Table 2–17, *Estimate of Available Nitrogen (as a Proportion of Total Nitrogen),* on page 38. At the sample prices for commercial fertilizer shown in this chart, the approximate value of the manure is $222/ha ($90/ac) assuming that all nutrients are needed by the crop.

Nutrient Management Plans

A nutrient management plan matches the nutrients available in manure, from cover crops, in commercial fertilizer and in the soil to the nutrients required by the crop (see Table 2-16, on page 37). Analysis of nutrients contained in the manure, along with soil test results and crop requirements, help to determine the application rate and additional commercial fertilizer requirements.

A nutrient management plan may restrict the rate of manure or fertilizer applied if that application brings certain risks, as shown below:

Criteria	Risk
Nitrogen	nitrate leaching into groundwater
Phosphorus	phosphate movement into surface water
Volume of liquid	direct runoff, carrying ammonia, phosphate and bacteria

Estimating Nutrients Available to the Crop From Average Values

The best way of determining the amount of each nutrient from manure is to analyze a sample. Unfor-

Table 2–16.
Average Amounts of Dry Matter, Nitrogen and Available Phosphate and Potash for Different Types of Organic Nutrient Sources

Type of Organic Nutrient Sources	% Dry Matter	Total Nitrogen	Ammonium Nitrogen	Available P_2O_5	Available K_2O	$N-P_2O_5-K_2O$ Value[1]	
		Liquid: kg/1,000 L (lb/1,000 gal)				$/1,000 L	$/1,000 gal
Beef[2]	6	2.8 (28)	1.5 (15)	0.7 (7.4)	1.9 (19.4)	2.85	12.90
Dairy: outside storage[3]	6	3 (30)	1.6 (16)	0.68 (6.4)	2.5 (24.8)	3.15	13.20
Dairy: under-barn storage[3]	8	4.1 (41)	2.1 (21)	0.8 (8.2)	3.2 (31.6)	4.05	16.75
Dairy heifers	11	5.0 (55)	2.5 (25)	1.2 (12.3)	3.5 (35)	4.95	24.95
Poultry layers	10	7.4 (74)	5.2 (52)	2.4 (23.9)	3.2 (32.4)	8.30	37.30
Swine: sows/weaners	3	3.5 (35)	2.4 (24)	0.9 (9.2)	1.6 (16.2)	3.65	16.45
Swine finishers	5	4.9 (49)	3.0 (30)	1.5 (14.7)	2.2 (21.6)	5.05	22.35
Swine finishers: wet/dry feeders	6.5	5.8 (58)	3.5 (35)	1.8 (18.4)	2.6 (25.9)	5.90	28.75
Liquid runoff	1.0	1.0 (10)	0.6 (6)	0.2 (1.8)	1.3 (13)	1.25	5.55
Liquid biosolids: anaerobic	4.4	2.8 (28)	0.9 (9)	1.3 (12.9)	0.0 (0)	2.05	9.65
		Solid: kg/tonne (lb/ton)				$/tonne	$/ton
Beef	28	7.2 (14.4)	0.8 (1.6)	2.1 (4.2)	6.1 (12.3)	5.80	4.95
Dairy	20	5.7 (11.4)	1.3 (2.7)	1.5 (3.0)	4.8 (9.7)	4.93	4.15
Poultry: layers	20	11.5 (23)	6.3 (12.8)	4.7 (9.4)	4.6 (9.3)	12.40	11.20
Poultry: broilers	> 50	30 (60)	3.8 (7.6)	12.4 (24.8)	15.9 (31.8)	26.10	22.65
Sheep	30	10.6 (21.2)	4.5 (9)	5.4 (10.9)	7.5 (15.1)	12.15	10.45
Horses	50	3.2 (6.4)	0.4 (0.8)	2.4 (4.8)	6.6 (13.2)	5.25	4.35

Source: OMAFRA NMAN 2001 Software

[1] Approximate value based on spring-applied manure, immediately incorporated, and on $N-P_2O_5-K_2O$ value/lb of $0.40–0.35–0.17.

[2] Includes some yard runoff.

[3] Includes milkhouse wastes.

tunately, this is not always possible, as in the case of a new barn. In this case, average values will provide an estimate of the nutrients available to the crop, when the nitrogen availability is adjusted for the time of application.

Table 2–16, above, provides the average results from manure analyses at the five accredited labs in Ontario over the past 6 years. Phosphate and potash values are reported as nutrients available to replace fertilizer nutrients. Nitrogen is reported as total N and ammonium N. The ammonium nitrogen in manure is chemically the same form of nitrogen as in many mineral fertilizers and is immediately available to the crop. Unfortunately, the ammonium form is also subject to loss by volatilization if not incorporated immediately. The balance of the nitrogen in manure is in the organic form, which becomes available to crops gradually as the organic compounds break down to release ammonium. The availability of manure N to the crop depends on the proportion of ammonium and organic N, the timing of application and the timing of incorporation.

Factors Affecting Availability of Manure Nitrogen to Crops

Manure from different farming systems contains varying proportions of organic and ammonium nitrogen. Liquid manure contains a higher proportion of the nitrogen in the ammonium form than solid manure. As soon as the manure is applied to the field, the ammonium N starts to volatilize into the air. This process continues until the manure is moved into the soil by incorporation or rainfall, or until the ammonium in the manure is depleted to the point that it is stable. Manures that are incorporated quickly will provide much more nitrogen to the crop.

Table 2–17.
Estimate of Available Nitrogen[1] (as a Proportion of Total Nitrogen[2])

	Incorporated (<24 hours)					Not Incorporated				
								Preplant		
Application Time	**Late Summer**	**Early Fall**	**Late Fall**	**Preplant**	**Side-Dress**	**Early Fall**	**Late Fall**	**Bare Soil**	**Residue**	**Side-dress**
Urea (commercial N)	0.1	0.2	0.5	1.0	1.0	0.1	0.4	0.85	0.75	0.85
Solid cattle/sheep	0.3	0.3	0.3	0.4	–	0.25	0.2	0.2	0.2	0.2
Solid poultry	0.3	0.4	0.5	0.6	–	0.3	0.3	0.3	0.3	0.3
Liquid cattle	0.3	0.4	0.5	0.6	0.7	0.3	0.4	0.5	0.55	0.6
Liquid swine	0.2	0.3	0.4	0.7	0.8	0.2	0.3	0.4	0.45	0.5
Liquid biosolids	0.3	0.4	0.5	0.6	0.7	0.3	0.4	0.5	0.55	0.6

Source: Beauchamp et al., University of Guelph, 2000

[1] Available N = Total Manure N applied x proportion available (assumes a spring-planted crop).

[2] Accounts for ammonia loss to atmosphere and mineralization of organic N. For manure incorporated within 3 days, use: (incorporated value + non-incorporated value)/2

Organic nitrogen is not available to the crop until it has been mineralized to the ammonium form by microbial action. This process occurs most quickly with warm temperatures and adequate moisture, and will almost stop when soil temperatures drop towards freezing. Nitrogen from solid manure applied just before planting may not be available in time to meet the requirements of the crop.

Ammonium nitrogen is further converted to nitrate by microbial action in the soil. Unlike ammonium, which will stick to soil particles, the nitrate ion can move freely with soil water.

Loss of nitrate nitrogen through leaching or denitrification will occur if manure is applied in the summer or early fall. The amount of loss will depend on how much nitrate is produced, which in turn depends on the time for nitrate to be produced from ammonium and organic N. Late summer applications of manure have a greater chance of nitrate losses than manure applied just before freeze-up or in the spring.

Table 2–17, *Estimate of Available Nitrogen (as a Proportion of Total Nitrogen)*, above, shows the proportion of available nitrogen from different materials depending on the time of application. To estimate the amount of nitrogen available to the crop, multiply the amount of manure nitrogen applied to the field by the availability factor appropriate for the manure type and application timing.

This table accounts for the volatilization of ammonium N into the air, the mineralization of organic N and the loss of nitrate through denitrification or leaching. A large part of the ammonium N will be lost to the air if manure is left on the surface of the soil, so the proportion of nitrogen available to the crop is greater with incorporated manure. Assumptions have been made concerning the proportion of nitrogen in the ammonium and organic forms (see Table 2–18, *Approximate Ammonium-Nitrogen Levels in Different Manure Types*, on page 39) and the availability of the organic nitrogen. Urea has been included as an example of how fertilizer nitrogen availability compares with that of manure.

The values in Table 2–16, on page 37, and Table 2–17, above, along with the manure application rates, can be used to estimate the amount of nitrogen available to the crop from manure applications at different timings. For example, if solid broiler manure is applied at 9 t/ha (4 t/ac) in spring on cereal residue, with no incorporation, the nitrogen available to the crop from manure would be 73.5 kg/ha (65.5 lb/ac). This is calculated by multiplying the total nitrogen content of the manure (22.5 kg/tonne or 54.6 lb/ton) by the application rate (9 t/ha or 4 t/ac), giving a total nitrogen application of 244.6 kg/ha (218.4 lb/ac). The availability factor for a spring preplant application is 0.3, and this, multiplied by the total N application, gives an available N of 73.4 kg/ha (65.5 lb/ac) (244.6 x 0.3 = 73.4 kg/ha or 218.4 x 0.3 = 65.5 lb/ac).

Manure Analysis

Manure analysis is necessary because the quantities of nutrients contained in manure vary from farm to farm, especially the phosphorus and potash components. Type of livestock, ration, bedding, added liquids and storage system all affect the final nutrient analysis. Fertilizer adjustments based on a manure analysis will be much more accurate than those based on average values.

Above-average levels of nitrogen and/or phosphorus in manure may be an indication that dietary protein or phosphorus is being fed at higher than required levels. Amino acid balancing for nitrogen, reducing the amount of phosphorus in the mineral supplements or the addition of phytase (an enzyme that increases phosphorus efficiency in the animal) may be methods that can help reduce these nutrients in manure.

A manure analysis is available from several laboratories in Ontario. An analysis should be performed after complete agitation or thorough mixing each time the storage is emptied (i.e., spring and fall). After several analyses, a trend in results should become evident, and sampling can be limited to major changes in ration or other management factors.

When sending a sample to the lab, fill a plastic jar (about 1-litre capacity) half-full, cover and place in a plastic bag and store in a cool place until shipping. Analysis should include total nitrogen, ammonium-nitrogen (NH_4-N), phosphorus, potassium and dry matter. Ontario labs send back analysis results with percentages for nitrogen, phosphorus, potassium and dry matter as well as mg/kg (or ppm) of ammonium nitrogen. On most reports, percentages of phosphorus and potassium from manure are converted to phosphate and potash equivalents, and commercial fertilizer reductions are given. The relation between total and available phosphorus and potash is the same for all application timings. When reading the report, note carefully whether you are reading total nutrient contents or available nutrients.

For more information on interpreting a manure analysis, see Appendix D, *Calculating Available Nutrients from a Manure Analysis*, on page 260.

Predicting and Managing Nutrient Losses From Manure

There are two nitrogen components in manure. Ammonium-nitrogen makes up the largest percentage of the nitrogen in liquid manure with approximate percentages listed by livestock type in Table 2–18, *Approximate Ammonium-Nitrogen Levels in Different Manure Types*, right. The organic nitrogen component is available over time as the organic matter breaks down, similar to a slow-release nitrogen fertilizer. About 20% to 30% of the organic nitrogen component of manure is assumed to be available to a growing crop in the year of application. The percentage is generally higher in poultry and lower for ruminant livestock manure.

Table 2–18.
Approximate Ammonium-Nitrogen Levels in Different Manure Types

Manure Type	Ammonium-Nitrogen
Liquid hog	66%
Liquid dairy	50%
Liquid beef	55%
Liquid poultry	70%
Biosolids	27%
Solid hog	30%
Solid dairy	25%
Solid beef	12%
Solid poultry	30%

Source: OMAFRA NMAN 2001 Software

Ammonium-nitrogen is immediately available to a growing crop but is also most easily lost to volatilization unless incorporated soon after application. Soil moisture and weather conditions will determine how quickly and how much loss to expect. These losses are highest during sunny, high-temperature days when soils are dry; losses are lowest when conditions are overcast and cold, when soils are moist or during rainy periods. Table 2–19, *Estimated Percentage of Ammonium-Nitrogen Lost Due to Weather and Soil Conditions*, on page 40, gives estimated losses due to weather and soil conditions only for the ammonium-nitrogen component of manure. With late fall-applied manure, the losses appear low since cooler temperatures minimize microbial action in soil, which minimizes conversion. Losses can be high due to runoff from late fall applications, especially when not incorporated. Denitrification and leaching losses of nitrogen are dealt with in the section *Nitrogen Risk Assessment*, on page 42.

Table 2–20, *Estimated Percentage of Organic Nitrogen Available in Year of Application*, on page 40, gives estimated nitrogen available from the organic nitrogen portion of the manure based on livestock type.

Long-Term Value of Manure

The long-term availability of phosphorus (P), potassium (K), magnesium, zinc or manganese from previous manure applications is best estimated by soil testing. Application of large quantities of manure

Table 2-19.
Estimated Percentage of Ammonium-Nitrogen Lost Due to Weather and Soil Conditions

Days After Application	Average	Cool (<10°C) Wet	Cool (<10°C) Dry	Warm (>25°C) Wet	Warm (>25°C) Dry
Incorporated within 1 day	25	10	15	25	50
Incorporated within 2 days	30	13	19	31	57
Incorporated within 3 days	35	15	22	38	65
Incorporated within 4 days	40	17	26	44	73
Incorporated within 5 days	45	20	30	50	80
Not incorporated	66	40	50	75	100
Injected (covered)	0	0	0	0	0
Spring/Summer/Early Fall					
Bare soil	66	40	50	75	90
Crop residue	50	30	35	60	70
Standing crop	35	25	25	40	50
Late fall-applied	25	25	25	N/A	N/A

Adapted from Beauchamp, University of Guelph, 1995.

over time can result in high levels of available P and K in soils. Manures also contribute other plant nutrients and organic matter to soil that may be of some long-term value.

Most of the available nitrogen in manure is used by the crop or is lost during the first growing season following application. The remaining organic nitrogen becomes available in small, diminishing quantities in the succeeding years. Generally, the amount of residual nitrogen from one application is too small to make a practical difference in nitrogen recommendations for a crop. However, where solid manure is applied regularly to the same field, there can be significant residual nitrogen available for a crop. The N soil test for corn or barley can be used to assess available nitrogen in succeeding years following application. The soil test for P and K should be used to measure residual phosphorus and potassium from manure applications.

Crop Requirements

Soil test results and yield goals will determine the maximum economic application rate and/or additional fertilizer requirements. Often soil test levels on livestock farms indicate that soil fertility levels are adequate or high and do not require additional fertility. One alternative to allow for manure application is to determine the nutrients removed by a crop and then match phosphorus and/or nitrogen from manure to determine an application rate that will not build soil test to excessive levels. Table 2-21, *Average Nutrient (N, P, K) Removal by Common Field Crops*, on page 41, will help determine the average nutrient removal for various crops.

Table 2-20.
Estimated Percentage of Organic Nitrogen Available in Year of Application

Liquid		Solid		
Poultry	All Other	Poultry	<50% dry matter	>50% dry matter
0.3	0.2	0.3	0.1	0.05

$$\text{Crop Removal} = (\text{Base Value}) \times \left(\frac{\text{Estimated Yield}}{\text{Base Yield}}\right)$$

If manure is applied to meet the entire nitrogen requirements of a corn crop, there will usually be more P and K applied than the crop will remove, and soil test levels will increase. For liquid manure, an application goal of two-thirds to three-quarters of the nitrogen requirements for a corn crop is a reasonable compromise. With solid manure, because of the high carbon content of the bedding material, the release of nitrogen is much less predictable. Due to difficulty in even application for both solid and liquid manure, starter fertilizer is still recommended unless soil test results indicate that no additional nutrients are needed.

Residual nitrogen from legume crops should be taken into account when determining additional nitrogen needs from manure or fertilizer (see Table 2-15, *Adjustment of Nitrogen Requirement Where Crops Containing Legumes Are Plowed Down*, on page 36). Manure applications to cereal crops, soybeans or canola should be done with caution, since too high a rate will increase the incidence of lodging. For summer application to standing crops such as corn or forages, rates should be kept below 45,000 L/ha (4,000 gal/ac) or 55-65 kg/ha (50-60 lb/ac) ammonium nitrogen. Application to forages should be completed as soon as possible after harvest to avoid potential nitrogen burn to new leaf growth. Older forage stands with higher grass content will benefit most from the manure nitrogen. Concentrated manures with high ammonium-nitrogen levels (for example, manure from covered storages or manure from swine barns with wet-dry feeders) should be avoided for application into standing crops.

Soil compaction is a problem for many growers. It leads to, among other things, poor drainage and decreased aeration. The best way to reduce or avoid soil compaction is to spread manure when the soil is dry. Keep loads below 4.5 tonnes (5 tons) per axle. Consider these points when selecting spreading

Table 2-21.
Average Nutrient (N, P, K) Removal by Common Field Crops

Crop	Base Yield	Removal Base Value (kg/ha)		
		N	P_2O_5	K_2O
Legume forage	11 t/ha (DM)	353	73	336
Grass forage	9 t/ha (DM)	196	56	196
Mixed forage	11 t/ha (DM)	314	73	336
Canola	3 t/ha	106	62	30
Corn silage	40 t/ha	231	103	215
Corn	9 t/ha	134	68	47
Wheat	5 t/ha	101	49	30
Wheat + straw	5 t/ha	165	59	138
Barley	4 t/ha	83	33	26
Barley + straw	4 t/ha	112	41	103
Oats	3 t/ha	61	21	17
Soybeans	3 t/ha	217	47	78

Source: Potash and Phosphate Institute,1997.

equipment and deciding when to spread manure (i.e., summer vs. spring vs. fall application). Spring spreading is often carried out on fields that are too wet, and it is not unusual for strips of stunted crops to show where the wheel tracks were.

Calibrating Spreaders

Calibrating manure application equipment is essential. Several methods can be used to measure spreading rates. Weighing a load of manure and measuring the area that load covers is one method of estimating the rate of application. Solid manure can be weighed by placing plastic sheets on the ground and liquid manure by using straight-walled pails for measuring depth of application. Overlap should also be considered, especially in irrigation systems. Table 2-22, *Calibrating Manure Spreaders*, right, gives an estimate of application rates while Table 2-23, *Densities of Different Types of Manure*, right, distinguishes between the densities of different types of manure. The OMAFRA Factsheet *How to Calibrate Your Manure Spreader*, Order No. 97-003, is available as a reference.

Environmental Concerns With Manure

Using manure to meet but not exceed crop nutrient needs will help minimize nutrient losses to the environment. However, take care to avoid the movement of manure into streams from erosion, surface and tile runoff.

Table 2-22.
Calibrating Manure Spreaders

Solid Manure Calibration[1]		Liquid Manure Calibration[2]		
Kg of Manure	Application Rate	Depth of Manure in Pail		Application Rate
(per sheet)	t/ha[3]	in.	mm	L/ha
0.5	3.6	1/10	2.5	25,000
0.9	7.2	1/8	3.2	32,000
1.4	10.8	1/4	6.4	64,000
1.8	14.3	3/8	9.5	95,000
2.3	17.9	1/2	12.7	127,000
3.2	25.1	5/8	15.9	159,000
4.5	35.8	3/4	19.1	191,000
6.8	53.8	1	25.4	254,000

[1] Using a 122 cm x 102 cm sheet (i.e. , plastic feedbag)
[2] Using a straight-walled pail
[3] tons per acre = tonnes per hectare x 0.45

Application to fields with steep slopes or impermeable soils can cause manure runoff when application rates are too high. For some soil types, several applications at lower rates may be necessary. Table 2-24, *Slope and Soil Texture Impact on Application Rate*, on page 42, will help determine the maximum rates for single applications of manure on your field as it relates to runoff potential.

The runoff potential can also be used to determine the minimum separation distance from streams and other watercourses.

Spreading manure in the winter and early spring is not recommended because of the potential for runoff to surface water. The fate of the first meltwater follow-

Table 2-23.
Densities of Different Types of Manure

Manure Type	Weight per Cubic Metre	Weight per Cubic Foot	Weight per Litre	Weight per Bushel
Liquid	1,000 kg	62 lb	1.0 kg	80 lb
Semi-solid	960 kg	60 lb	0.9 kg	76 lb
Thick solid	800 kg	50 lb	0.8 kg	64 lb
Light solid	560 kg	35 lb	0.6 kg	45 lb

Table 2–24.
Slope and Soil Texture Impact on Application Rate

Runoff Potential

Soil Texture	**Maximum Field Slope** < 0.5%	0.5–2%	2–5%	> 5%
Sand	very low	very low	very low	low
Loam	very low	low	low	moderate
Clay loam	low	moderate	moderate	high
Clay	moderate	high	high	high

Maximum Application Rate
Use the runoff potential to determine the maximum allowable application rate for your field.

Runoff Potential	**Surface Applied (L/ha)**	**Incorporated or Pretilled (L/ha)**
High	50,500	76,400
Moderate	76,400	102,200
Low	102,200	126,900
Very low	126,900	152,800

Source: *Best Management Practices: Nutrient Management Practices,* Order No. BMP 05, OMAFRA and Agriculture Canada, 1998.

ing manure application determines whether this will be a problem or not. Do not incorporate this practice into a nutrient management plan. In years when winter spreading may be necessary, take care to select fields where there is no risk of runoff to surface water.

Rain can cause organic nitrogen to wash into streams if manure has been applied to unprotected cropland. Phosphorus attached to soil particles can be carried to streams by soil erosion. Conservation practices can reduce the chances of nutrients polluting waterways.

Manure should not be applied near watercourses. Runoff potential is influenced by field slope and soil texture. Table 2–25, *Determining Minimum Separation Distance From Watercourses,* right, can be used to determine the runoff potential to establish a minimum separation distance. In a no-till system that includes a 3 m (10 ft) wide buffer strip along the watercourse, the separation distance can be reduced to 9 m (30 ft) for liquid manure and 4.5 m (15 ft) for solid manure.

Flow in tile drains can become contaminated if manure enters a catchbasin or travels through soil cracks to the tiles. With liquid manure, maintain a 9 m (30 ft) buffer around a catchbasin or surface inlet (4.5 m or 15 ft with solid manure).

Table 2–25.
Determining Minimum Separation Distance From Watercourses

Runoff Potential	**Surface Applied (m)**		**Incorporated or Pretilled (m)**	
	Liquid	**Solid**	**Liquid**	**Solid**
High	30	15	18	9
Moderate	23	11	14	7
Low	15	8	9	5
Very low	9	5	9	5

Source: *Best Management Practices: Nutrient Management Practices,* Order No. BMP 05, OMAFRA and Agriculture Canada, 1998.

Apply liquid manure onto tiled fields using caution. If field tiles are running, liquid manure can travel through macropores and contaminate surface water sources. If there is any history of tile contamination via soil cracks or macropores, tillage prior to application and/or monitoring of tile outlets is strongly recommended.

Applications of nutrients in manure or fertilizer in excess of crop requirements can result in contamination of groundwater, particularly on shallow soils over bedrock, soils with a water table close to the surface or very sandy soils where leaching is a concern. Groundwater contamination can occur by mass flow through cracks and holes to groundwater or through leaching of nitrates through the soil. Contamination can also occur if manure seeps directly into inadequately protected water wells. Manure should not be applied within 15 m (50 ft) of drilled wells, or 30 m (100 ft) of dug wells.

Large livestock operations on small land bases pose special challenges. To avoid over-application of nutrients, especially on fields near the barn, a nutrient management plan should be completed. It may be necessary to sign agreements with neighbouring farms to ensure the availability of fields for manure spreading.

Nitrogen Risk Assessment

The nitrogen cycle, with its many forms of nitrogen, is a complicated process that is influenced by many factors including weather, soil and physical, chemical and biological processes. Use the optimum amount of nitrogen, keeping in perspective, however, that any nitrogen not used has the potential to leach below the root zone, volatilize into the atmosphere or denitrify (potentially to nitrous oxide — a greenhouse gas).

The movement of nitrogen to groundwater sources has also become an important issue in many communities. Groundwater and aquifer vulnerability studies are being conducted in many locations across Ontario with results that indicate that agricultural impact can be significant. As a result, a nitrogen index is being developed to help minimize the risk of nitrogen leaching below the root zone, especially in coarse-textured and shallow-to-bedrock soils. Management practices that include cover crops with late summer and early fall manure applications as well as timing nitrogen applications as close to crop nitrogen requirements and/or reduced total nitrogen applications are all methods that help reduce potential nitrogen loss.

Nitrate that could potentially leach out of the rooting zone includes nitrogen that is applied in excess of crop removal and nitrogen from manure or biosolids applied in the summer or fall. In Ontario, most of the drainage to groundwater occurs during late fall to early spring, when precipitation exceeds evaporation. On sandy, well-drained soils, much of the nitrate present in the fall could be leached into groundwater if drainage occurs. On heavier soils, more of the loss will be through denitrification. Minimizing the amount of nitrate present in the soil in the fall will reduce both types of loss.

Management practices to reduce the risk of nitrate losses include:

- growing cover crops whenever manure is applied in late summer or early fall
- timing nitrogen applications close to crop nitrogen uptake
- reduced total nitrogen applications

For future information on nitrogen risk assessment, once developed, refer to the OMAFRA Web site at www.gov.on.ca/OMAFRA/english.

Phosphorus Risk Assessment

The risk of surface water contamination by phosphorus may be increased at higher soil test phosphorus levels. However, since phosphorus binds tightly to soil particles, the movement of soil from a field by erosion is also a major factor in determining the risk of surface-water contamination. Because of this, the risk of surface-water contamination by phosphorus cannot be based on a soil-test phosphorus level alone.

When soil test results indicate that no additional phosphorus is required to achieve maximum economic yield, but manure nutrients will still be applied (Excessive), the risk of phosphorus contamination to surface water increases. Phosphorus in surface-water sources increases eutrophication or aquatic plant growth, which leads to oxygen fluctuations and decreased ability for the water source to support aquatic life. To address the environmental risk of additional phosphorus application when soil test levels are adequate, a phosphorus index has been developed.

For more information on phosphorus risk assessment, see Appendix C, *Phosphorus Index*, on page 258.

Biosolids and Residuals Use on Agricultural Land

Biosolids are nutrient-rich, processed organic materials derived from municipal wastewater treatment processes. They usually contain mineral and organic nitrogen, phosphorus, potash, organic matter and micronutrients such as zinc, magnesium and copper. The use of biosolids as part of a farm nutrient management package can reduce the demand for commercial fertilizers, improve soil fertility and enhance soil structure, moisture retention and permeability. Biosolids are ideal for crops such as corn, soybeans, cereals and forage crops.

Residuals include pulp and paper mill fibre residuals, grain processing by-products and many other organic-based wastes, as well as some inorganic materials such as lime rejects from the sugar-processing industry. Each type of waste has unique characteristics that have the potential to benefit soil quality and/or crop production. Some may have limitations that producers should be aware of. For example, a paper-mill residual that is low in nitrogen and high in carbon may temporarily tie up soil nitrogen when applied. This has the potential to cause a nitrogen deficiency in the crop. Producers should be provided with information on the nutrient content and availability and possible negative impacts of biosolids and residuals use.

Biosolids and residuals land application is regulated under Part V of the *Environmental Protection Act*. The use of biosolids and residuals on agricultural land is regulated by the Ontario Ministry of the Environment. The *Guidelines for the Utilization of Biosolids and Other Wastes on Agricultural Land, March 1996* sets out the guidelines related to biosolids and residuals quality, the application site criteria and the application of these materials on agricultural land. A Certificate of Approval is required before land application of any regulated waste material can occur. When properly used, biosolids and residuals can provide a valuable supplementation to a farm nutrient management program.

Table 2–26.
Fertilizer Materials – Primary Nutrients

Nitrogen Materials	Form	% Nitrogen (N)	Salt Index[1]
Ammonium nitrate	dry	30 to 34	15.3
Calcium ammonium nitrate	dry	27	15.3
Urea	dry	45 to 46	8.1
Ammonium sulfate	dry	21	16.3
Urea-ammonium nitrate	liquid	28	11.3
Anhydrous ammonia	liquid[2]	82	2.9
Phosphate Materials		**% Phosphate (P_2O_5)**	
Single superphosphate		20	2.0
Triple superphosphate		44 to 46	1.1
Monoammonium phosphate		48 to 52	2.0
Diammonium phosphate (18-46-0)		46	2.3
Ammonium polyphosphate (10-34-0)		34	2.3
Potash Materials		**% Potash (K_2O)**	
Muriate of potash		60 to 62	9.7
Sulfate of potash		50	4.3
Sulfate of potash magnesia (11% Mg)		22	9.9
Potassium nitrate (13-0-44)		44	6.1

[1] Expressed per unit (100 lb) of nutrient.

[2] Liquid under pressure.

Table 2–27.
Fertilizer Materials –
Secondary and Micronutrients

Magnesium (Mg)	
Dolomitic limestone	6–13% Mg
Epsom salts (magnesium sulfate)	10.5% Mg
Sulfate of potash magnesia	11% Mg
Boron (B)	
Sodium borate	12–21% B
Solubor	20.5% B
Copper (Cu)	
Copper sulfate	13–25% Cu
Copper chelates	5–13% Cu
Manganese (Mn)	
Manganese sulfate	26–28% Mn
Molybdenum (Mo)	
Sodium molybdate	39% Mo
Zinc (Zn)	
Zinc sulfate	36% Zn
Zinc chelates	7–14% Zn
Zinc oxysulfate	18–36% Zn

Fertilizer Materials

Nitrogen fertilizer materials are available in dry or liquid forms. Although there are some limitations to use of these materials (see the section *Toxicity of Fertilizer Materials*, on page 45), in most cases the different sources will produce equal yields. The choice of material should therefore depend on availability, equipment for handling and cost per kilogram of nitrogen, plus the cost of application.

First calculate the cost per kilogram of nitrogen for various sources delivered to your farm. Using the rate of application, the cost per hectare can be determined. Add to this the cost of application per hectare before deciding which nitrogen source to use.

Where separate additions of nitrogen are referred to in the recommendations, kilograms of elemental nitrogen (N), not kilograms of materials, are used. Table 2-26, *Fertilizer Materials – Primary Nutrients*, above, and Table 2–27, *Fertilizer Materials – Secondary and Micronutrients*, above, show the percentage of fertilizer nutrient contained in different materials.

Various fertilizer companies have available, in addition to the micronutrient sources listed in Table 2–27, premixes containing one or more micronutrients.

A wide range of liquid fertilizers is used in Ontario. While these are generally more expensive per unit of nutrient than dry granular fertilizers, liquid fertilizers are easier to handle and can be metered and placed more precisely. Characteristics of the most commonly used liquid fertilizers are included in Table 2–28, *Characteristics of Common Liquid Fertilizers*, on page 45.

Soluble Salts in Farm Soils

High concentrations of water-soluble salts in soils can prevent or delay the germination of seeds and can kill established plants or seriously retard their growth.

Ontario soils are naturally low in soluble salts. Soluble salts therefore rarely cause a problem in crop production and are not routinely measured in soil tests.

Soluble salts in soils can result from excessive applications of fertilizers and manures, runoff of salts

Table 2–28. Characteristics of Common Liquid Fertilizers

Analyses	Weight/ US Gallon (lb)	Weight/Imp. Gallon (lb)	Weight/ Litre (lb)	Imp. Gallons/ Tonne	US Gallons/ Tonne	Litre/ Tonne
8-25-3	11.11	13.35	2.94	165.1	198.4	749.9
6-18-6	10.69	12.85	2.83	171.6	206.2	779.0
3-11-11	10.45	12.55	2.76	175.7	211.0	798.8
9-9-9	10.49	12.60	2.77	175.0	210.2	795.9
7-7-7	10.41	12.5	2.75	176.4	211.8	801.7
6-24-6	11.07	13.30	2.93	165.8	199.2	752.4
9-18-9	11.07	13.30	2.92	165.8	199.2	755
5-10-15	10.7	12.85	2.83	171.6	206.0	799
2-10-15	10.62	12.75	2.81	172.9	207.6	784.6
10-34-0	11.5–11.74	14.0–14.1	3.08–3.1	157.5–156.4	189.2–187.8	715.8–711.2
28%	10.65	12.8	2.82	172.2	207.0	781.8
Aqua	7.49	9	1.98	245	294.3	1,113.4
54% phos. acid	13.15	15.8	3.48	139.5	167.7	633.5

1 Imperial gallon = 1.201 US gallons = 4.546 litres

1 US gallon = .8326 Imperial gallons = 3.785 litres

applied to roads and chemical spills on farmland. High concentrations of soluble salts in or near a fertilizer band can cause serious reductions in early plant growth without seriously affecting the salt concentrations in the remainder of the soil. A given amount of salt in a soil provides a higher salt concentration in soil water if the amount of water is small. Soluble salts also interfere with the uptake of water by plants. For these reasons, plant growth is most affected by soluble salts in periods of dry conditions at planting.

Soluble salts can be measured readily in the laboratory by measuring the electrical conductivity of a soil water slurry. The higher the concentration of water soluble salts, the higher the conductivity. Table 2–29, *Soil Conductivity Reading Interpretation*, on page 46, provides an interpretation of soil conductivity reading as read in Ontario field soils in a 2:1 water:soil paste, the procedure used by the OMAFRA-accredited soil testing program.

For greenhouse soils, the OMAFRA-accredited soil test uses larger soil samples and measures conductivity on a saturation extract. For greenhouse crops using this method, conductivity readings up to 3.5 millisiemens/cm are acceptable.

Toxicity of Fertilizer Materials

All fertilizer salts are toxic to germinating seeds and to plant roots if applied in sufficient concentration near the seed. Fertilizers vary in toxicity per unit of plant nutrient due to:

- differences in the amount of salts contained in the fertilizer per unit of plant nutrient
- differences in the solubility of the salts in the soil
- the presence of specific materials or elements that are particularly toxic (for example, ammonia and boron). Many nitrogen fertilizers, although they have a relatively low salt index, release free ammonia into the soil.

Nitrogen Fertilizers

Ammonium nitrate, monoammonium phosphate and ammonium sulphate are similar in toxicity and much safer than anhydrous ammonia, aqua ammonia or urea. Diammonium phosphate is more toxic than monoammonium phosphate but less toxic than urea. More care should be taken, particularly with sensitive seeds such as beans or peas, and on coarse-textured soil (sand and sandy loam), than is required with ammonium nitrate or monoammonium phosphate.

Because anhydrous ammonia and aqua ammonia are extremely toxic fertilizers, they should not be placed near seeds. It is preferable to make preplant applications crossways to the direction in which the crop will be planted. Stand reductions may still occur over the band in very dry soils or if planting takes place too soon after application.

Table 2–29.
Soil Conductivity Reading Interpretation

Conductivity "salt" reading (millisiemens/cm)	Rating	Plant Response
0–0.25	L	Suitable for most plants if recommended amounts of fertilizer are used.
0.26–0.45	M	Suitable for most plants if recommended amounts of fertilizer are used.
0.46–0.70	H	May reduce emergence and cause slight-to-severe damage to salt-sensitive plants.
0.71–1.00	E	May prevent emergence and cause slight-to-severe damage to most plants.
1.00	E	Expected to cause severe damage to most plants.

Urea is toxic when banded with or near the seed but is safe when broadcast at rates normally used. Fertilizers containing more than half as much nitrogen as phosphate frequently contain urea.

Phosphate Fertilizers

Phosphate fertilizers are usually low in toxicity due to a large portion of the phosphate being precipitated in the soil before it can reach the plant roots. The concentration of phosphorus in soil solution at any one time is very low. No limit is normally set for the safe rate at which phosphates may be applied with, or near, the seed of field-grown crops.

Diammonium phosphate is more toxic than other phosphate fertilizers. See the section *Nitrogen Fertilizers*, on page 45.

Potash Fertilizers

Muriate of potash (KCl) is the most common source of potassium in fertilizers and is less toxic per unit of plant nutrients than most nitrogen fertilizers.

Sulphate of potash (K_2SO_4) is less toxic than muriate of potash.

Sulphate of potash-magnesia has approximately the same toxicity per unit of potassium as muriate of potash.

Potassium nitrate is one of the safer sources of potassium.

Table 2–30, *Maximum Safe Rates of Nutrients*, on page 47, provides the maximum safe rates of nutrients for various crop scenarios. The safe rates listed in this table are for practices occurring singly. If two or more fertilizer applications are combined, the additive effect may cause damage to the crop even though the individual applications are below the threshold for injury.

Fertilizers Containing Micronutrients

Fertilizers containing micronutrients (boron, copper, iron, manganese or zinc) are more toxic than the same grades without micronutrients, and maximum safe rates should be reduced. Boron is particularly toxic and should not be banded.

Guidelines for Safe Rates of Nutrients Applied at Seeding

Fertilizer toxicity varies widely, depending on the amount of soil moisture. Injury will occur most frequently on light-textured (sandy or gravelly) soils low in organic matter and with dry weather. To ensure completely safe rates of banded fertilizer for all seeding conditions would require extremely low rates of application. The maximum safe rates suggested here will most likely reduce or delay germination, or retard growth in up to 10% of the cases where they are used. It is generally advisable to use lower rates of fertilizer at seeding than those listed in Table 2–30, *Maximum Safe Rates of Nutrients*, on page 47. If fertilizer requirements are high, it may be better to broadcast most of the fertilizer required and to band only a small portion at seeding. Fertilizers containing the micronutrients boron, copper, iron, manganese and zinc are more toxic, and the safe rates recommended will be lower than those shown in this table.

Some growers are using much higher rates of banded fertilizer than are listed here, with no apparent problem. Crops are able to tolerate much higher rates of fertilizer with adequate moisture, but it is impossible to predict before planting when adverse conditions for germination will occur. Keeping below the maximum safe rates is the surest way to ensure a good start for the crop.

Foliar Fertilizers

Micronutrients can be supplied to the crop through foliar fertilization, particularly in instances where a deficiency is due to a tie-up of these nutrients in the soil (i.e., manganese). Quantities of nutrient that can be applied this way are limited because of the danger of burning the leaves. Care must be taken when combining nutrients that the resulting solution is not too concentrated. Check pesticide labels before mixing foliar nutrients with any pesticide spray.

Table 2–30.
Maximum Safe Rates of Nutrients

Spring oats and barley (fertilizer with the seed)	
Sands and sandy loam soils	35 kg nitrogen or 55 kg (nitrogen + potash) per hectare. If **diammonium phosphate** (18-46-0) is the N source, 20 kg nitrogen or 35 kg (nitrogen + potash) per hectare. If **urea** is the N source, 10 kg nitrogen or 30 kg (nitrogen + potash) per hectare.[1]
Loams, silt or clay loams	45 kg nitrogen or 70 kg (nitrogen + potash) per hectare. If **diammonium phosphate** (18-46-0) is the N source, 30 kg nitrogen or 55 kg (nitrogen + potash) per hectare. If **urea** is the N source, 10 kg nitrogen or 30 kg (nitrogen + potash) per hectare.[1]
Winter wheat, triticale or barley (fertilizer with the seed)	
All soils	15 kg nitrogen or 30 kg (nitrogen + potash) per hectare. **Diammonium phosphate** (18-46-0) or **urea** should not be drilled with the seed of fall-seeded cereals.[1]
Corn (fertilizer with the seed)	
All soils	7 kg (nitrogen + potash) per hectare in 1-m rows. **Diammonium phosphate** or **urea** should not be applied with the seed of corn. At row widths other than 1 m, the rate may be adjusted to provide the same maximum concentration in the row (in 50-cm rows, the safe rate = 100/50 x 7 = 14 kg (nitrogen + potash)/ha).
Corn (fertilizer banded 5 cm to the side and 5 cm below the seed)	
All soils	55 kg nitrogen or 90 kg (nitrogen + potash) per hectare. If **urea** is the N source, 40 kg nitrogen or 60 kg (nitrogen + potash) per hectare. If more than 55 kg nitrogen per hectare is banded, the band should be at least 15 cm from the seed. At row widths other than 1 m, the rate may be adjusted to provide the same maximum concentration in the row (in 50-cm rows the safe rate = 100/50 x 55 = 110 kg N/ha).
Corn (fertilizer broadcast)	
Sands and sandy loam soils	If **urea** is the N source, 200 kg nitrogen or 250 kg (nitrogen + potash) per hectare.
Canola (fertilizer with the seed)	
	Up to 20 kg/ha phosphate fertilizer may be drilled with the seed as superphosphate or monoammonium phosphate. Nitrogen (except in the form of monoammonium phosphate) and potash should not be applied with the seed.
Flax (no fertilizer with seed)	
All soils	Rates recommended are normally safe when broadcast.
Peas, beans and soybeans (no fertilizer with seed)	
All soils	(fertilizer banded 5 cm to the side and 5 cm below the seed in 1-m rows) 30 kg nitrogen or 90 kg (nitrogen + potash) per hectare. Rates recommended are normally safe when broadcast.
100 kg/ha = 90 lbs/ac	

[1] Fertilizers containing more than half as much nitrogen as phosphate (e.g., 16-16-16) frequently contain urea. Note that fertilizers containing urea are not suitable for banding at seeding in many cases.

Calculating Fertilizer Requirements

The mineral fertilizer required for optimum crop production is calculated by deducting the nutrients in manure and legumes from the total nutrients required. Further, it is often beneficial to separate the starter component of the fertilizer, which is generally high in phosphorus, from the balance of the nitrogen and potassium.

An example of this type of calculation is provided in Table 2-31, *Example Calculation for Fertilizer Application Requirements*, right. In this example, the total broadcast fertilizer required is 66 kg N/ha, or 143 kg/ha of urea. The starter fertilizer application could also have been reduced and still meet the crop requirements.

To use this table, enter the nitrogen, phosphate and potash requirements on the top line. Deduct the nutrients from legumes, manure or other organic sources to determine the amount of mineral fertilizer that will be required to add to meet the total requirements.

The choice of starter fertilizer will depend on the crop to be grown, the mineral fertilizer requirements and the equipment available. It is often equally efficient to apply part of the fertilizer as a starter and broadcast the rest, as it is to apply all the fertilizer through the planter or drill. The advantage to this program is savings in time and labour, and less risk of fertilizer injury to the seedling.

Table 2-31.
Example Calculation for Fertilizer Application Requirements

	N	P_2O_5	K_2O
	kg/ha		
Requirements	157	50	81
less legumes	45	0	0
less manure	34	34	157
less sewage biosolids	0	0	0
Total Mineral Fertilizer Requirements	78	17	0
less starter fertilizer	12	49	25
less side-dressed fertilizer	0	0	0
Total Broadcast Fertilizer Requirements	66	0	0

Crop to be grown: corn
Previous crop: barley with red clover
Manure applied: solid dairy manure (22.4 t/ha or 10 t/ac) spring incorporated
Other organic nutrient sources: none
Starter fertilizer: 157 kg/ha (140 lb/ac) 8-32-16
Supplemental N: none

Deduct applications of starter fertilizer and side-dressed fertilizer from the total mineral fertilizer requirement. Any balance remaining should be broadcast. If only very small numbers remain, you may want to consider adjusting the rates of one of the other nutrient sources, ignoring the small residuals or planning a fertilizer application that will meet multi-year requirements (P & K only).

3. Corn

Corn is grown widely across Southern Ontario. Over the years 1996–2000, grain corn acreage averaged 717,000 ha (1.77 million ac) with an average yield of 7.34 t/ha (117 bu/ac). An additional 121,000 ha is grown as corn silage for livestock feed. Grain corn produced within the province is used for both feed (65%) and industrial uses (35%). The total commercial value of the Ontario corn crop exceeds $800 million annually.

Tillage Systems

Conventional Tillage

Conventional tillage for corn in Ontario consists of fall moldboard plowing followed in spring by secondary tillage, usually with the field cultivator or tandem disc. Most moldboard plowing is targeted for an operating depth of 15 cm (6 in.); plowing deeper than this can often result in unwanted mixing of subsoil into the seedbed. The more uniform and level a field is left after fall plowing, the greater the opportunity to reduce secondary tillage costs and improve planter performance. Most growers realize that the lack of surface residue in conventional tillage exposes their fields to greater erosion risks from water and wind. On slopes, the tillage act itself can be responsible for causing large quantities of topsoil to move to lower slope positions.

Fall Mulch Tillage

The chisel plow has been the most widely adopted fall mulch tillage tool in Ontario with tandem and offset discs also being used extensively in some areas. Tillage research trials conducted across Ontario over the past 20 years have generally shown that disking often resulted in more favourable soil conditions and higher corn yields than chisel plowing. Table 3–1, *The Impact of Fall Tillage Systems on Grain Corn Yield*, below, summarizes the corn yield data from these sites.

Table 3–1.
The Impact of Fall Tillage Systems on Grain Corn Yield
All tillage plots received secondary tillage in the spring prior to corn planting.
(Trials conducted following various previous crops in the period 1979–96).

					Fall Tillage Systems Corn Yield		
Location	**County**	**Soil**	**Previous Crop**	**# of Years**	**Moldboard**	**Chisel**	**Offset Disc**
Milton	Halton	clay loam	corn	3	7.34 t/ha (117 bu/ac)	6.84 t/ha (109 bu/ac)	6.84 t/ha (109 bu/ac)
Elora	Wellington	silt loam	corn	7	7.72 t/ha (123 bu/ac)	7.34 t/ha (117 bu/ac)	7.59 t/ha (121 bu/ac)
Elora	Wellington	silt loam	soybeans	2	7.40 t/ha (118 bu/ac)	7.40 t/ha (118 bu/ac)	7.78 t/ha (124 bu/ac)
Comber	Essex	clay loam	soybeans	3	7.78 t/ha (124 bu/ac)	7.34 t/ha (117 bu/ac)	7.78 t/ha (124 bu/ac)
Morpeth	Kent	clay	soybeans	2	6.77 t/ha (108 bu/ac)	6.15 t/ha (98 bu/ac)	6.90 t/ha (110 bu/ac)
Average				n = 17	7.407 t/ha (118 bu/ac)	7.017 t/ha (112 bu/ac)	7.407 t/ha (118 bu/ac)

Source: T. Vyn, K. Janovicek, D. Hooker and D. Young, University of Guelph.

Table 3–2.
The Impact of Fall Tillage Systems on Grain Corn Yield
Moldboard and chisel plots received spring secondary tillage;
fall tandem disc-only plots were planted directly in the spring without any secondary tillage.

					Tillage Systems: Corn Yield		
Location	**County**	**Soil**	**Previous Crop**	**# of years**	**Moldboard**	**Chisel**	**Fall Tandem Disc Only**
Alvinston	Lambton	clay	soybeans	3	5.96 t/ha (95 bu/ac)	5.39 t/ha (86 bu/ac)	5.71 t/ha (91 bu/ac)
Fingal	Elgin	silty clay loam	soybeans	3	9.97 t/ha (159 bu/ac)	9.66 t/ha (154 bu/ac)	9.66 t/ha (154 bu/ac)
Centralia	Huron	silt loam	wheat straw baled	3	9.16 t/ha (146 bu/ac)	8.72 t/ha (139 bu/ac)	8.84 t/ha (141 bu/ac)
Wyoming	Lambton	silty clay loam	wheat straw baled	3	9.97 t/ha (159 bu/ac)	9.72 t/ha (155 bu/ac)	9.85 t/ha (157 bu/ac)
Average				n = 12	8.78 t/ha (140 bu/ac)	8.41 t/ha (134 bu/ac)	8.53 t/ha (136 bu/ac)

Source: T. Vyn, K. Janovicek, D. Hooker and G. Opuku, University of Guelph.

Chisel plowing with twisted shovel teeth may leave the soil quite ridged. This can lead to extra costs in secondary tillage (more passes), uneven seedbeds and occasionally excessive soil drying. Using sweep teeth on all or part of the chisel plow overcomes some of these problems as does adding a levelling bar or harrows to the rear of the chisel plow. Practising timely secondary tillage in the spring is also advantageous.

When disking is done in such a way as to leave the soil level in the fall, single-pass corn planting (no secondary tillage) becomes a viable option in the spring and is a good technique for reducing tillage costs. Table 3–2, *The Impact of Fall Tillage Systems on Grain Corn Yield*, above, outlines research conducted in Ontario where this approach was taken. On those sites where fall chisel plowing and secondary tillage were compared, the tandem disc-only treatment generally produced higher yields and had significantly lower operating costs. On average, using only the tandem disc yielded within 5 bu of the conventional tillage system.

Spring Mulch Tillage

The best practice for reducing erosion and input costs is to refrain from fall tillage. Producers working on heavy soils where crop residues are high following corn, wheat or other crops may be apprehensive about leaving soils untouched in the fall. However, following soybeans, there is little justification for doing fall tillage on most fields in Ontario. Table 3–3, *Tillage System Effects on Grain Corn Yield Following Soybeans*, right, illustrates that even on finely textured soils, spring tillage alone (using a field cultivator for 2 passes) was generally sufficient when corn followed soybeans in the rotation. Other demonstration trials established on medium- and coarse-textured soils have arrived at the same conclusion.

When **corn follows soybeans**, systems that involve more than spring cultivation only often do not produce enough extra corn to pay for the fall tillage operation.

Grower experience with spring mulch tillage systems has indicated that working undisturbed soils in the spring obtained better results when using high clear-

Table 3–3.
Tillage System Effects on Grain Corn Yield Following Soybeans
At Fingal and Alvinston, Ontario, 1994–96 averages.

	Fingal (silty clay loam soil)	**Alvinston (clay soil)**
	Grain Corn Yields @ 15.5%	
Fall moldboard + spring tillage	9.97 t/ha (159 bu/ac)	6.02 t/ha (96 bu/ac)
Spring tillage only	9.78 t/ha (156 bu/ac)	6.02 t/ha (96 bu/ac)
No tillage	9.65 t/ha (154 bu/ac)	5.65 t/ha (90 bu/ac)

Source: T. Vyn, D. Hooker and C. Swanton, University of Guelph.

Table 3-4.
Strip Tillage for Corn After Winter Wheat [1]

Tillage System[2]	Soil Moisture in Early May	Yield	
		Wyoming	Centralia
Fall moldboard	23.3%	9.97 t/ha (159 bu/ac)	9.22 t/ha (147 bu/ac)
Fall zone-till	25.6%	9.97 t/ha (159 bu/ac)	8.72 t/ha (139 bu/ac)
No-till	29.8%	9.35 t/ha (149 bu/ac)	8.47 t/ha (135 bu/ac)

Source: T.J. Vyn, 1997, University of Guelph

[1] (baled straw) (1994–96).

[2] Moldboard and chisel-plowed plots were cultivated and packed in spring. Fall disc and zone-till plots were planted directly without any secondary tillage in spring. All treatments were planted the same day.

ance tines, narrow teeth and/or when packers or rollers are used in conjunction with the field cultivator.

Fall Strip Tillage

The concept of performing fall tillage confined to narrow zones corresponding to next year's corn rows has received considerable attention during the past few years. The method is to prepare strips of soil that are loosened, cleared of residue and hopefully somewhat elevated, while leaving the rest of the field covered with crop residue and therefore protected. The next spring, these strips are drier, less dense and more suited to "no-till" planting. Research conducted at the University of Guelph over the period 1994–96 employed strip tillage in the fall in winter wheat stubble.

Table 3-4, *Strip Tillage for Corn After Winter Wheat,* above, indicates that on fine textured soils, strip tillage in the fall generally produced yields that were better than no-till, but only at Wyoming did they equal yields obtained with the conventional moldboard system. Both producers and researchers have done a wide range of testing with strip tillage systems. Results do not consistently show a yield advantage for the strip tillage system over no-till. However, when soil moisture levels were measured in the university plots, the strip-tilled zones were consistently drier in early May than in the undisturbed no-till plots. Yield responses in side-by-side trials have not always indicated a benefit to strip tillage, but producers with large acreage, poorly drained soils or high surface residues may gain a consistent benefit from strip tillage in terms of planting timeliness, emergence and early corn growth.

The strip tillage system can also provide an opportunity for reducing compaction and/or improving drainage by conducting deep tillage. In some cases, recommendations are made to till as deep as 30–35 cm (12–14 in.). There is limited evidence to support deep strip tillage for corn. However, a strip tillage system automatically eliminates traffic on the deep-tilled zones at least until the next harvest, allowing for some soil stabilization before being again exposed to wheel traffic.

No-Till Systems

Key management issues within no-till systems for corn are:

- soil drainage
- crop rotation
- residue management
- weed control
- fertilizer placement
- soil compaction
- disease/insect management (see the section *No-Till Systems,* on page 15.)

Soil Drainage

Good internal drainage improves the probability that soils will dry and allow for timely planting of corn in a no-till system. Drainage lessens the risk that soils will become saturated and prone to poor root growth and function, especially early in the season. Producers often discover that no-till is very difficult to do successfully in fine textured soils that are not systematically tile drained.

Crop Rotation

Rotations can be viewed as replacement for tillage. Narrow rotations such as continuous corn do not lend themselves to no-till regardless of what else is done correctly. Sound crop rotations, including a wider range of crops such as legumes and forages, improve soil structure and generally make no-till more successful.

Residue Management

Reducing tillage costs for corn, improving net profits and enhancing the long-term health of the soil requires corn producers to make decisions about how best to handle crop residues, particularly wheat straw. Many of these decisions require some action before heading to the wheat field with the combine. Where a producer's intention is to manage wheat straw to facilitate no-till or reduced tillage corn production, it is best to remove the wheat straw from the field.

**Table 3–5.
The Effect of Wheat Straw Levels on
No-Till Corn Yields[1, 2]**

Tillage System/Straw Level	Corn Yield
No-till /all straw and stubble remain	9.16 t/ha (146 bu/ac)
No-till /straw baled but stubble remains	9.35 t/ha (149 bu/ac)
No-till/straw baled and stubble cut and removed	9.91 t/ha (158 bu/ac)
Moldboard/straw baled but stubble remains	9.97 t/ha (159 bu/ac)

Source: T. Vyn, G. Opuku and C. Swanton, University of Guelph

[1] Average 1994–96. Wyoming, Ontario.

[2] Stubble heights were approximately 25–30 cm (10–12 in.) except for plots where stubble was cut and removed.

Table 3–5, *The Effect of Wheat Straw Levels on No-Till Corn Yields,* above, outlines the corn yields from tillage trials where three different levels of straw were left on the field and corn was no-till planted the following year. Removing straw from fields, especially in high-yielding wheat crops and on heavier-textured soils increases the potential for no-till corn yields to equal those of moldboard plowing.

Where straw removal is not an option, uniform spreading of the straw and chaff is critical for no-till or reduced tillage success in corn. Even where straw is left in the windrow, ensure that chaff is spread as widely and uniformly as possible during combining. In cool, wet springs, the lower soil temperatures, poorer growth and potential slug damage brought on by mats of decaying wheat residue often result in yield losses that could have been avoided by uniform residue spreading.

Where the risks of water and wind erosion are low, the benefits of returning all the straw might outweigh the advantages of reducing tillage. For farms where erosion potential is higher, adopting a reduced tillage system, even with the need to remove some straw, is probably more sustainable. Another option is using a system where wheat fields receive a small amount of tillage to partially incorporate straw while still leaving the soil surface largely protected.

The impact of adding nitrogen to assist in straw breakdown was tested by researchers at the University of Guelph. Results indicate that where nitrogen was spread on wheat straw in the fall, the straw did not decay faster. In addition, the soil nitrogen levels were not higher on these plots when tested the following spring compared to the plots that did not receive nitrogen.

Weed Control

For corn yield potential to be realized, optimum weed control is required. Extra management in no-till cropping systems may be needed to control perennial weeds and weed species that are new (due to a shift in weed populations). Spring pre-plant burndown treatments are critical in allowing the crop to develop without interference during critical early growth phases.

Fertilizer Placement

Studies in Ontario indicate that nutrient stratification (nutrients concentrated near the soil surface) may occur in long-term, no-till fields. Without the option to incorporate or mix dry fertilizer material in the no-till system, fertilizer placement becomes increasingly important. Results have shown that the size of the yield response to planter-banded potassium (K) in no-till often exceeds the response on side-by-side moldboard plots.

Another important factor to consider is that no-till soils are often cooler and less aerated than in conventional tillage. These conditions lead to a rate of nitrogen mineralization that is slower in no-till than in tilled ground.

> Applying 35 kg/ha (31 lb/ac) of nitrogen in the starter on no-till corn planters is recommended in order to overcome the slower nitrogen mineralization often present in no-till soils.

Soil Compaction

Soil compaction is often cited as one of the reasons no-till may yield less than conventional tillage corn. An option for enhancing corn yields in reduced tillage systems may include extensive loosening deeper into the soil profile. This can be done without disrupting much of the crop residue on the soil surface and can be confined to zones where next year's corn rows will be planted. University of Guelph researchers tested deep in-row ripping in 1998–2000 at sites near Granton and Ridgetown. Table 3–6, *The Effects of Tillage Systems on Corn Yields Following Winter Wheat,* on page 53, illustrates that deep loosening either provided no yield benefit or not enough to pay for the cost of the deep tillage. Some growers have claimed benefits of deep ripping on poorly drained areas or in areas where soil compaction was excessive, such as headlands.

Table 3-6.
The Effects of Tillage Systems on Corn Yields Following Winter Wheat[1]

Tillage System	Granton (loam–clay loam soil)	Ridgetown (clay loam soil)
Fall moldboard	11.35 t/ha (181 bu/ac)	7.78 t/ha (124 bu/ac)
Deep fall zone-till (30 cm)	10.79 t/ha (172 bu/ac)	8.15 t/ha (130 bu/ac)
No-till (3-coulters)	10.73 t/ha (171 bu/ac)	7.65 t/ha (122 bu/ac)
No-till (row cleaners)	10.85 t/ha (173 bu/ac)	7.78 t/ha (124 bu/ac)

Source: T. Vyn, B. Deen K. Janovicek, D. Young, University of Guelph

[1] Average of 1998–2000. Granton and Ridgetown, Ontario.

Hybrid Selection

Maturity Ratings

Corn development is driven primarily by temperature, and this is especially true during the planting-to-silking period. Unlike soybeans, day length has little effect on the rate at which corn develops. The Ontario Crop Heat Unit System has been developed to calculate the impact of temperature on corn development. Ontario crop heat units (CHUs) are calculated based on daily maximum and minimum temperatures and allow for a numerical rating of growing seasons, geographical locations and corn hybrids. This system allows growers to select hybrids with CHU ratings that have a high probability of reaching maturity before a killing frost.

Table 3-7, *Average Seasonal Accumulations of Crop Heat Units From Various Sites Across Ontario,* on page 54, outlines the accumulated crop heat units over the course of an average growing season at various locations across Ontario.

Producers who record high and low temperatures can use Table 3-8, *Daily Crop Heat Unit Accumulations Based on Maximum and Minimum Temperatures,* on page 55, to calculate CHUs for their own farm.

Other jurisdictions use different systems for quantifying the effect of temperature on corn development and for rating corn hybrid maturity. Unfortunately, these systems are unique, and true mathematical conversions from one to the other are not possible. Table 3-9, *Approximate Conversions Between Three Systems of Measuring Heat Accumulation in a Growing Season,* on page 56, provides values to assist in making reasonable comparisons between the different systems.

Selecting the Most Profitable Hybrids

Hybrid selection is probably the single most important management decision in determining cropping profitability. Corn hybrids with superior yielding potential have been continuously introduced into the market place over the past 40 years. Yield increases of approximately 1.5% per year have been occurring. To remain competitive, growers must introduce new hybrids to their acreage on a regular basis. The following are a few key considerations:

Maturity and CHUs

Using crop heat unit ratings, select hybrids that will reach maturity (black layer) before season-ending frosts traditionally occur in your area. Table 3-7, on page 54, Figure 3-1, *Crop Heat Units Available for Corn Production,* on page 57, or farm records will provide the heat units normally accumulated in a given area. For example, for someone living near Brucefield, the long-term data from Table 3-7 indicates heat unit accumulation averages 2,823 CHUs. Notice that the average start date for CHU accumulation is May 16. If a grower has the ability to plant early, where emergence can be expected before May 16, consider selecting a hybrid with a heat unit rating 100–150 CHUs higher than the full season (2,800) recommendation. Note that by the end of May, 2 weeks later, 230 heat units have usually been accumulated. If planting has not occurred by this date, selecting a lower heat unit hybrid is recommended (see the section *Switch Dates,* on page 58).

Highest Yield

In any given hybrid performance trial, there may be a 1.88–2.50 t/ha (30–40 bu/ac) difference in yield between the highest- and lowest-yielding hybrids. This emphasizes the importance of obtaining reliable information on hybrid yield potential and adaptability. Growers must be able to sort out information from two main sources: performance trial data and strip trial data.

The Ontario Corn Committee conducts corn hybrid performance trials each year across the province. These performance trials include the majority of available hybrids. Generally, these trials are set up so that a given set of hybrids, for a certain heat unit range, are tested at three to four locations. These trials give a good indication of yield potential but because they are limited to a few locations, do a poor job of indicating hybrid adaptability over a wide range of conditions. For this sort of data, growers need to turn to strip trials that are conducted on a larger number of sites across a wide range of environments. Seed companies usually summarize these strip trials.

Table 3–7.
Average Seasonal Accumulations of Crop Heat Units From Various Sites Across Ontario

Location	Average Season Start[1]	Crop Heat Units Accumulated to:																						Average Season End[2]
		May	June				July				August					September				October				
		30	6	13	20	27	4	11	18	25	1	8	15	22	29	5	12	19	26	3	10	17		
Harrow	May 8	388	536	701	870	1041	1225	1411	1602	1799	1988	2178	2360	2539	2718	2893	3055	3198	3324	3430	3515	3534		Oct 11
Ridgetown	May 11	324	465	621	781	947	1125	1305	1491	1681	1864	2048	2223	2396	2568	2737	2894	3031	3154	3255	3332	3342		Oct 10
Vineland	May 17	201	321	467	621	783	957	1138	1326	1517	1703	1891	2071	2245	2418	2587	2744	2877	2997	3098	3176	3188		Oct 10
Sarnia	May 13	262	392	537	686	839	1010	1185	1366	1551	1729	1909	2082	2250	2420	2582	2736	2869	2981	3076	3146	-		Oct 9
Belleville	May 14	270	406	555	712	875	1048	1228	1414	1605	1791	1978	2156	2325	2494	2656	2804	2928	3038	3128	3139	-		Oct 4
Cornwall	May 13	287	420	564	722	885	1057	1233	1417	1603	1786	1971	2144	2308	2468	2623	2762	2877	2979	3054	-	-		Oct 1
Delhi	May 13	274	406	554	705	860	1028	1198	1372	1552	1725	1901	2067	2228	2390	2547	2692	2813	2923	3006	3036	-		Oct 4
Brockville	May 15	249	376	517	668	826	993	1166	1347	1531	1711	1892	2064	2226	2386	2540	2680	2796	2898	2982	2992	-		Oct 3
London	May 15	252	377	518	663	815	979	1145	1317	1494	1665	1837	1999	2157	2314	2466	2604	2720	2821	2899	-	-		Oct 2
Ottawa	May 16	247	379	521	674	834	1002	1175	1356	1537	1711	1890	2057	2214	2369	2517	2650	2758	2850	2885	-	-		Sep 28
Brucefield	May 16	230	353	491	632	778	937	1097	1265	1436	1601	1768	1924	2077	2230	2379	2516	2631	2734	2813	2823	-		Oct 3
Cheneaux	May 17	222	346	485	632	789	953	1123	1300	1477	1650	1827	1993	2150	2304	2452	2583	2688	2780	2814	-	-		Sep 28
Kemptville	May 17	216	341	478	625	779	940	1106	1281	1456	1626	1798	1959	2108	2258	2402	2530	2631	2712	2731	-	-		Sep 26
Guelph	May 19	178	295	430	568	712	867	1027	1193	1364	1527	1693	1848	1997	2148	2294	2427	2536	2632	2682	-	-		Sep 30
Peterborough	May 19	193	312	445	584	729	884	1043	1210	1379	1542	1707	1861	2005	2150	2289	2416	2519	2601	-	-	-		Sep 24
Midhurst	May 20	170	281	411	546	689	842	1001	1165	1336	1500	1666	1822	1972	2123	2263	2392	2492	2571	2596	-	-		Sep 26
Wiarton	May 26	87	169	279	399	529	672	824	984	1149	1308	1470	1621	1766	1913	2053	2180	2283	2373	2402	-	-		Sep 28
North Bay	May 21	155	265	390	525	667	821	980	1146	1314	1477	1638	1790	1931	2073	2205	2321	2384	-	-	-	-		Sep 17
Mount Forest	May 23	121	213	334	456	587	733	879	1034	1191	1341	1497	1637	1773	1914	2048	2166	2264	2342	-	-	-		Sep 25
Thunder Bay	June 3	30	82	158	250	364	491	630	774	925	1068	1213	1346	1473	1598	1709	1789	-	-	-	-	-		Sep 10

Source: A. Bootsma, Agriculture and Agri-Food Canada, and D.M. Brown, University of Guelph.

[1] The season start date (date to start accumulating CHUs) is determined as: (1) the last day of three consecutive days, with daily mean air temperatures equal to or greater than 12.8°C (55°F); and (2) the starting date for this three-day period each year occurred after the date the 30-year average daily mean air temperature reached 10°C (50°C) in the spring for each weather station site.

[2] The season-ending date (date to stop accumulating CHUs) is the earlier date of either: (1) the first occurrence of –2°C (28°F); or (2) the date when the 30-year average daily mean air temperature dropped to 12°C (54°F) or lower.

Table 3–8.
Daily Crop Heat Unit Accumulations Based on Maximum and Minimum Temperatures

Daily CHU Values for ˚C Temperature Recordings

		Daily Recorded Minimum Temperature																			
	(˚C)	<5	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Daily Recorded Maximum Temperature	≤ 10	0	1	1	2	3	4	5	:	:	:	:	:	:	:	:	:	:	:	:	:	:
	11	2	2	3	4	5	6	7	8	:	:	:	:	:	:	:	:	:	:	:	:	:
	12	3	4	5	5	6	7	8	9	10	:	:	:	:	:	:	:	:	:	:	:	:
	13	5	5	6	7	8	9	10	11	11	12	:	:	:	:	:	:	:	:	:	:	:
	14	6	6	7	8	9	10	11	12	13	14	15	:	:	:	:	:	:	:	:	:	:
	15	7	8	9	10	10	11	12	13	14	15	16	17	:	:	:	:	:	:	:	:	:
	16	8	9	10	11	12	13	13	14	15	16	17	18	19	:	:	:	:	:	:	:	:
	17	10	10	11	12	13	14	15	16	16	17	18	19	20	21	:	:	:	:	:	:	:
	18	11	11	12	13	14	15	16	17	17	18	19	20	21	22	23	:	:	:	:	:	:
	19	12	12	13	14	15	16	17	17	18	19	20	21	22	23	24	25	:	:	:	:	:
	20	12	13	14	15	16	17	17	18	19	20	21	22	23	24	25	26	26	:	:	:	:
	21	13	14	15	16	16	17	18	19	20	21	22	23	24	25	25	26	27	28	:	:	:
	22	14	14	15	16	17	18	19	20	21	22	23	23	24	25	26	27	28	29	30	:	:
	23	15	15	16	17	18	19	20	20	21	22	23	24	25	26	27	28	29	29	30	31	:
	24	15	16	16	17	18	19	20	21	22	23	24	25	25	26	27	28	29	30	31	32	33
	25	16	16	17	18	19	20	21	21	22	23	24	25	26	27	28	29	30	30	31	32	33
	26	16	16	17	18	19	20	21	22	23	24	24	25	26	27	28	29	30	31	32	33	33
	27	16	17	18	18	19	20	21	22	23	24	25	26	27	27	28	29	30	31	32	33	34
	28	16	17	18	19	20	20	21	22	23	24	25	26	27	28	29	29	30	31	32	33	34
	29	16	17	18	19	20	21	21	22	23	24	25	26	27	28	29	30	30	31	32	33	34
	30	17	17	18	19	20	21	22	22	23	24	25	26	27	28	29	30	31	31	32	33	34
	31	16	17	18	19	20	21	21	22	23	24	25	26	27	28	29	30	30	31	32	33	34
	32	16	17	18	19	20	20	21	22	23	24	25	26	27	28	29	29	30	31	32	33	34
	33	16	17	17	18	19	20	21	22	23	24	25	26	26	27	28	29	30	31	32	33	34
	34	16	16	17	18	19	20	21	22	23	23	24	25	26	27	28	29	30	31	32	32	33

Many growers find it valuable to have a corn hybrid strip trial on their own farm. This allows new, high-yielding potential hybrids to be tested against those proven performers in the farming practice. However, it is important to remember that reliable hybrid selections require more than one test site even if that site is on the grower's own farm. Growers should look for 2-year data that originate from many sites (preferably more than 30) before making decisions about hybrids that will be planted on a significant portion of their acreage.

> Never purchase a hybrid without consulting performance data.

The Ontario Corn Committee publishes the *Hybrid Performance Trial Report* each December. This information is also available on the Internet at the Ontario Corn Producers Web site at www.ontariocorn.org.

Strip trials results from many seed companies are also being compiled by the Ontario Soil and Crop

Table 3–9.
Approximate Conversions Between Three Systems of Measuring Heat Accumulation in a Growing Season

Ontario Crop Heat Units (CHUs)	Corn Relative Maturity (CRM)	Growing Degree Days (Base 10) (GDD or GDU)
2,400	75	1,670
2,500	78	1,780
2,600	82	1,870
2,700	85	1,970
2,800	89	2,075
2,900	93	2,175
3,000	97	2,280
3,100	100	2,380
3,200	104	2,480
3,300	107	2,585
3,400	110	2,685

Improvement Association on their Web site at www.ontariosoilcrop.org.

Workhorses vs. Racehorses

Corn hybrids are often classified as "workhorses" or "racehorses." Hybrids that produce above-average yield under good conditions but below average under poor conditions are considered racehorses, while those that have relatively consistent yields in both low- and high-yielding conditions are considered workhorses. Most hybrids that are considered to be variable performers (racehorses) have specific defects that cause them to yield lower than average when exposed to certain conditions. Growers can avoid some of the risk associated with hybrid selection by taking time to find out as much as possible about a hybrid's past performance. Select hybrids that complement each other because they have different specific weaknesses. For example, when selecting two full-season hybrids with high yield potential for earliest planting, ensure that they don't both score low for stalk strength.

Standability

While selecting hybrids that have suitable maturity ratings and outstanding yield potential, evaluate hybrid selections for standability. This trait is particularly important where significant field drying is expected. If drying facilities are available on the farm and harvesting at relatively high moisture levels (>26%) is an option, standability may be less critical. Traits associated with improved hybrid standability include resistance to stalk rot and leaf blights, genetic stalk strength (a thick stalk rind), short plant height, lower ear placement and high late-season plant health.

One of the most significant advancements in improved standability has been the introduction of Bt hybrids that are resistant to European corn borer. On a provincial average, Bt hybrids have generally resulted in enough yield increase over their non-Bt counterparts to pay for the additional cost of the Bt seed. Corn grown in areas of the province where corn borer pressure is traditionally high and in situations where corn is being planted earlier or later than the majority of the surrounding corn often benefits significantly from having the Bt gene.

For further information on European corn borer management using Bt hybrids, refer to the section *European Corn Borer*, on page 80.

Harvest Moistures and Drying Costs

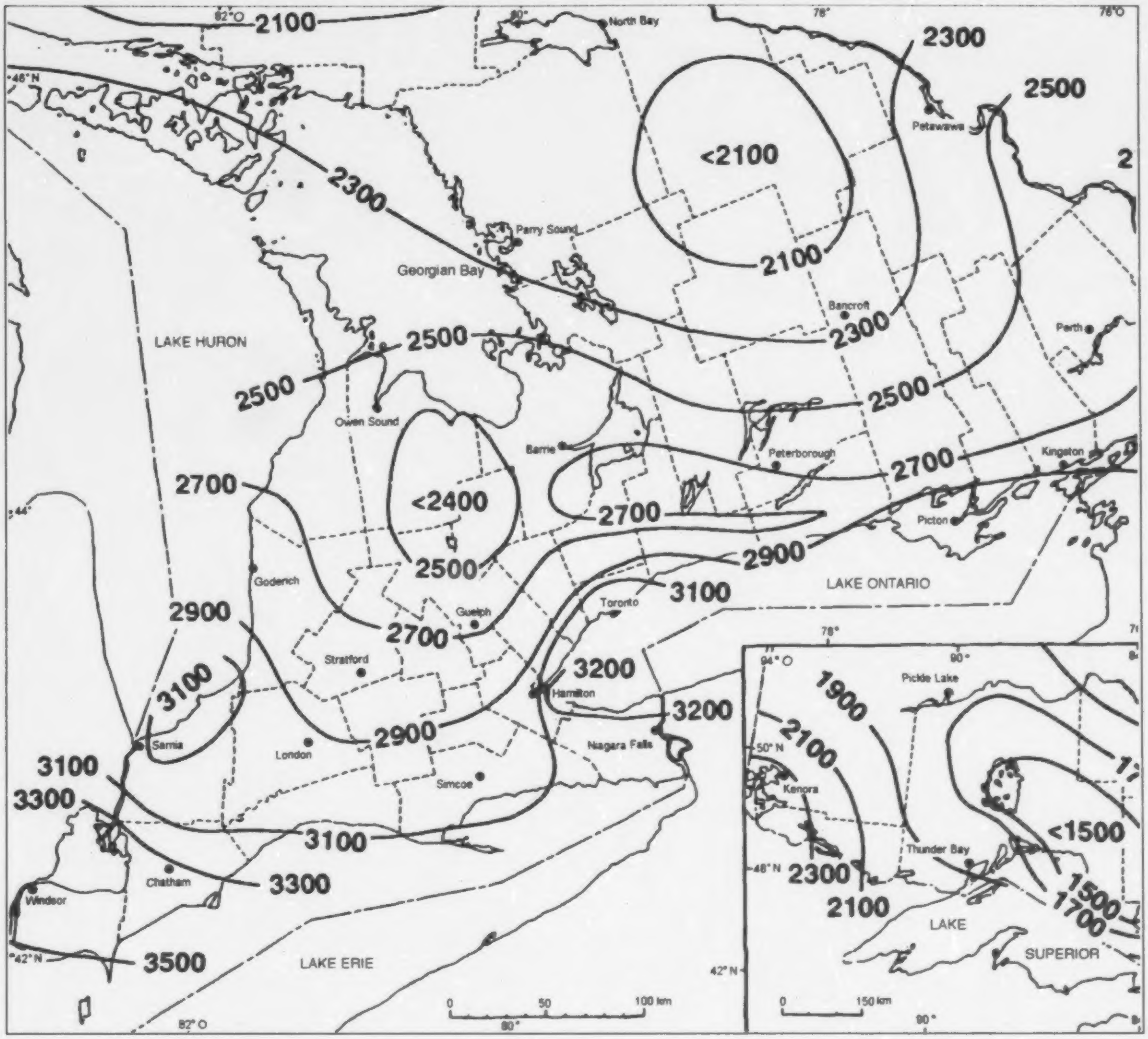
Hybrid selection may also be influenced by desired harvest moistures. In situations where corn is stored as high moisture grain (e.g., 28%), growers have more opportunity to maximize returns by growing full season, high-yielding hybrids. Where corn is dried for storage, growers should evaluate the impact that high harvest moistures may have on net returns. For example, any potential gains in net returns from a hybrid that yields 0.31 t/ha (5 bu/ac) greater than another may be eliminated by the increased drying charges.

Selecting Hybrids for Silage

When choosing hybrids specifically for whole-plant silage, a yield advantage can usually be obtained by selecting hybrids rated 100 to 200 heat units higher than those selected for grain. Hybrids should be selected for high silage yields with improved digestible energy. Silage-only and dual-purpose corn hybrids are marketed. Dual-purpose hybrids may provide some flexibility where grain harvest needs to be an option, such as when the silo is full.

Without sufficient independent data, it is very difficult to compare and select corn silage hybrids between companies. Choose hybrids from the top of a seed company's research for their hybrids-based ratings for silage yield, whole plant digestibility, fibre and starch digestibility.

Various models are used to compare the economic value of corn silage hybrids. The University of Wisconsin has developed "Milk Per Acre" and "Milk Per Ton" calculations using their Milk 2000 program to combine the traits of silage yield, digestibilities, fibre, starch, crude protein and intake potential into a sin-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Petawawa
Parry Sound
Georgian Bay
Bancroft
Perth
LAKE HURON
Owen Sound
Barrie
Peterborough
Kingston
Picton
Goderich
Guelph
Toronto
LAKE ONTARIO
Stratford
Hamilton
Niagara Falls
Sarnia
London
Simcoe
Chatham
Windsor
LAKE ERIE
46° N
44°
42° N
82° O
80°
78°
76° O
0
50
100 km
1900
2100
2300
2100
<1500
1500
1700
Pickle Lake
Kenora
Thunder Bay
LAKE
SUPERIOR
94° O
90°
50° N
48° N
150 km

Figure 3–1.

Crop Heat Units Available for Corn Production

This map is based on weather data from 1961–90. The average crop heat unit value will be reached 50% of the time.

gle measure. Milk per ton measures quality, while milk per acre combines yield and quality.

Switching to Shorter Season Hybrids

Field conditions may delay planting and warrant consideration of switching to less than full-season hybrids. Factors to consider in this decision include yield potential of shorter season hybrids, test weight concerns, drying costs and late-season harvesting capabilities. Grain corn obtains 90% of its total grain weight by one-half milk line, a maturity stage that even late-planted, full-season hybrids reach in most years. Switching to shorter-season hybrids may be a reasonable alternative from a grain yield perspective if earlier hybrids can produce within 10% of the full-season hybrid's yield. Generally, this is a more favourable proposition when growing 3,000 CHU hybrids as the full-season selections, which allows for switching to hybrids that are 100–150 heat units less without sacrificing excessive yield. If, on the other hand, the full season hybrids are in the 2,650-CHU range, the odds of dropping to a hybrid 100 heat units less without giving up more than 10% yield are poor.

Test Weight Concerns

Lower test weights often result if end-of-season frosts occur before late-planted corn has reached maturity (black layer). Consider test weight potential when selecting hybrids for planting in a late spring. Potential dockage from delivering lower bushel weight corn to an elevator or end user is shown in Table 3–10, *Grain Corn*

Table 3–10.
Grain Corn Test Weights and Potential Dockage[1]

Grade	Test Weight Minimum (kg/ha)	Test Weight Minimum (lb/bu)	Potential Dockage $/t
1	68.0	55.6	.00
2	66.0	54.1	.00
3	64.0	52.6	0.79
4	62.0	51.0	3.94
5	58.0	47.7	7.88

[1] Based on 2001 market. Potential dockage may vary considerably depending on year and location.

Test Weights and Potential Dockage, above. Farming operations that handle and feed all of their own corn may be unaffected by test weight concerns and may choose to remain with full-season hybrids longer into the planting season. Experience and research from 1992 and 2000 indicated there was little or no correlation between test weight and livestock feed value. Producers who deliver all their corn to elevators or processors may want to switch to earlier hybrids to increase the potential for suitable test weights at harvest. Producers in shorter-season areas who fear significant yield losses by switching to earlier-maturing hybrids may consider staying with full-season hybrids but switching to hybrids that have higher test weight scores.

Drying Costs

Full-season hybrids and/or late plantings predispose the grower to higher drying costs at harvest. Any potential yield advantage that could be obtained from staying with later-maturing hybrids must be weighed against additional drying costs. Research conducted at Michigan State University in the 1990s is outlined in Table 3–11, *The Effect of Growing Early, Mid- and Late-Maturing Hybrids on Yield, Harvest Moisture and Net Returns Across Three Zones in Michigan,* right. Yield, harvest moisture and net returns after drying were evaluated by varying the yield, harvest moisture and net returns after drying, for hybrids of different maturity across several zones within the state. Results confirm that although later-maturing hybrids consistently outyielded earlier hybrids, drying costs generally offset any advantage in terms of net returns. When there are low-cost drying alternatives or the possibility of storing high-moisture corn on-farm, there may be less incentive to switch to shorter-season hybrids than when producers must rely on commercial drying. If the elevator charges $12.80 CDN per tonne ($0.33 CDN per bushel) to dry corn from 25% to 15.5% but charges $15.36 CDN per tonne ($0.39 CDN per bushel) to dry from 30% to 15.5% moisture, then the higher moisture corn must yield at least 0.19 t/ha (3 bu/ac) more to cover the extra drying costs.

Table 3–11.
The Effect of Growing Early, Mid- and Late-Maturing Hybrids on Yield, Harvest Moisture and Net Returns Across Three Zones in Michigan[1]

	Hybrid Maturity	Zone 1 3,200 CHUs	Zone 2 3,100 CHUs	Zone 3 2,900 CHUs
Yield	Early	10.35 t/ha (165 bu/ac)	10.16 t/ha (162 bu/ac)	9.66 t/ha (154 bu/ac)
	Mid	10.79 t/ha (172 bu/ac)	10.73 t/ha (171 bu/ac)	9.97 t/ha (159 bu/ac)
	Late	10.98 t/ha (175 bu/ac)	10.97 t/ha (175 bu/ha)	10.16 t/ha (162 bu/ac)
Moisture	Early	19.4%	20.8%	21.7%
	Mid	21.9%	24.3%	24.2%
	Late	24.6%	26.7%	28.2%
Net Returns After Drying	Early	$970.91/ha ($393.08/ac)	$941.96/ha ($381.36/ac)	$890.83/ha ($360.66/ac)
	Mid	$987.98/ha ($399.99/ac)	$956.38/ha ($387.20/ac)	$896.34/ha ($362.89/ac)
	Late	$975.97/ha ($395.13/ac)	$955.87/ha ($386.99/ac)	$873.27/ha ($353.55/ac)

Source: K. Dysinger, S. Canty and J. Kells. 1998. Michigan State University. *Extension Bulletin E-431.*

[1] Average 1990–96. Prices in US$.

Harvesting

Sticking with high-yielding, later-maturing hybrids may present some logistical harvest concerns. Ensure that fields that are planted to potentially delayed hybrids are well drained and have good load-bearing capacities to facilitate harvesting in less than ideal conditions late in the season. Avoid planting later-maturing hybrids in the areas of the province that are more prone to November snow. The snow adheres to leaves and husks, making harvest impossible until a change in the weather occurs.

Switch Dates

Pioneer Hi-Bred International Inc. conducted extensive research across the northern corn belt to define the optimal date where producers should switch away from full-season hybrids. Some of this data is summarized in Table 3–12, *Recommended Dates to Switch From Full-Season Hybrids Across Various Heat Unit Zones,* on page 59. This collection of long-term data took into account yields for hybrids of various maturity ratings as well as deductions for test weight and drying. The switch date indicates the planting date when earlier-maturing hybrids surpass full-season hybrids in terms of net returns (gross returns less drying and test weight deductions).

Table 3-12.
Recommended Dates to Switch From Full-Season Hybrids Across Various Heat Unit Zones

Heat Unit Zone	Switch Date
3,125–3,300	Early June
2,950–3,150	May 20–25
2,800–3,075	May 20–25

Source: Adapted from R. Iragavarapu. *Basing Hybrid Maturity on Long-Term Data*. Pioneer Hi-Bred International Inc.

Growing hybrids with a range in maturity builds some insurance against both silking time stresses and end-of-season risks. However, making significant shifts to earlier hybrids should be reserved in the southwest (>3,000 CHUs) until June 1; in the mid-maturity corn growing areas (2,700–3,000 CHUs) until May 25 and in the shorter-season areas (<2,700 CHUs) until May 20.

A general rule has been to reduce hybrid maturity by 100 CHUs for every week that planting gets postponed beyond the cut-off date for full-season hybrids.

These are intended as general guidelines with fine-tuning for the individual farm based on the factors discussed above and upon consultation with seed company representatives.

Planting

Seeding Date

The best yields are usually obtained from corn planted in late April and the first half of May, because the crop is able to use the full growing season. Early planting also results in earlier maturity in the fall, reducing the risk of damage from an early fall frost or adverse weather at harvest. The optimum planting date is on or before May 7 in southwestern Ontario and May 10 in central and eastern Ontario. Delaying planting past the optimum date can result in yield reductions averaging 40 kg/ha per day.

Depending on the total number of days required to plant the farm's entire corn acreage, it is generally necessary to start planting corn well before the optimum date. Producers wanting to plant corn significantly earlier than optimum dates (i.e., April 15–25) should remember that soil temperatures need to reach a minimum of 10°C (50°F) before germination and emergence will occur. The average daily temperature is estimated by taking a temperature measurement around 11:30 a.m. using a 10 cm (4 in.) soil thermometer. If average soil temperatures are at or beyond 10°C (50°F), the soil conditions are favourable, and the weather forecast is predicting average to above-average temperatures, then early planting of at least a portion of the corn crop is recommended. After April 26 (May 1 in areas receiving less than 2,700 CHUs), it is generally advisable to pay less attention to soil temperature and to plant as soil moisture conditions permit.

Population

The plant populations discussed in this section are suggested final plant stands (see Table 3-13, *Seed Spacing to Achieve Various Populations*, on page 60). Since not all seeds emerge, it is necessary to seed at slightly higher rates. When planting early in the season or when the soil is cold, a seeding rate 10% higher than the desired final stand is recommended. When soils are warmer, an adjustment of 5% is sufficient.

In Ontario, corn has commonly been grown at populations of 64,000–74,000 plants/ha (26,000–30,000 plants/ac). These populations can produce good yields over a wide range of growing conditions without excessive lodging. In recent years, hybrids have been developed that tolerate higher plant densities without excessive lodging or barrenness. Research has shown that when old and new hybrids are grown side by side under very low populations, they yield almost identically. Higher yield responses occur as newer hybrids are grown at higher densities. Much of the historical yield improvement has come from developing hybrids that excel under higher densities. Some of the most recent hybrids report having economically optimum populations of 74,000–86,000 plants/ha (30,000–35,000 plants/ac). Seek out seed company data to fine-tune hybrid management and planting density.

Growers are concerned that increased seeding rates do not always result in greater yield potential. This is a valid concern, particularly on drought-susceptible fields where water availability, not light interception, is almost always the yield-limiting factor. Some savings can be obtained by adjusting populations downward in these situations. Research from the U.S. indicates that the optimum final plant population in the Midwest Corn Belt is 67,000 plants/ha (27,160 plants/ac). These researchers also predicted, based on their work, that for every 9.4 t/ha (15 bu/ac) increase in a field's yield potential (or parts of fields), economically optimal populations increased by 1,112 plants/ha (450 plants/ac).

In Ontario, it is common to aim for higher average final stands than in the U.S. Midwest. The most productive fields should be near the upper end of the plant population range for the hybrids being planted.

Table 3–13.
Seed Spacing to Achieve Various Populations

Final plants/ha	Final plants/ac	Row Width: cm (in.)													
		38	(15)	51	(20)	56	(22)	71	(28)	76	(30)	91	(36)	97	(38)
54,300	22,000	48	(19.0)	36	(14.3)	33	(13.0)	26	(10.2)	24	(9.5)	20	(7.9)	19	(7.5)
59,300	24,000	44	(17.4)	33	(13.1)	30	(11.9)	24	(9.3)	22	(8.7)	18	(7.2)	18	(6.9)
64,200	26,000	41	(16.1)	31	(12.1)	28	(11.0)	22	(8.6)	20	(8.1)	17	(6.7)	16	(6.4)
69,200	28,000	38	(14.9)	29	(11.2)	26	(10.2)	20	(8.0)	19	(7.5)	16	(6.2)	15	(5.9)
74,100	30,000	35	(13.9)	27	(10.5)	24	(9.5)	19	(7.5)	18	(7.0)	15	(5.8)	14	(5.5)
79,000	32,000	33	(13.1)	25	(9.8)	23	(8.9)	18	(7.0)	17	(6.6)	14	(5.4)	13	(5.2)
84,000	34,000	31	(12.3)	23	(9.2)	21	(8.4)	17	(6.6)	16	(6.1)	13	(5.1)	12	(4.9)

1 ha = 2.47 ac; 1 cm = 0.39 in.

In shorter-season areas of the province, where smaller-stature hybrids are grown, populations may be under even more pressure to remain high to maximize light interception and optimize yields. Yield increases from increased plant densities have generally been lowest in the warmer regions of Ontario (over 2,900 heat units).

Since lodging is of less concern for whole-plant corn silage, higher plant populations (10%) than those for grain corn have often been recommended. Research from Cornell University indicates that for silage growers who had been adopting ultra-high populations — 111,200–123,500 plants/ha (45,000–50,000 seeds/ac), there were no advantages for any of the hybrids tested to having stands of more than 86,500 plants/ha (35,000 plants/ac). It was also noted that a steady decline in silage digestibility occurred across all hybrids as populations increased. Producers should also note that there is increasing genetic diversity among silage hybrids and that optimum populations may be very hybrid specific.

Planting Depth

The first rule of corn-planting depth is to plant securely into moisture. However, a few other considerations allow for some fine-tuning of planting depth. Overly shallow planting of corn, that is, less than 3 cm (1.25 in.) deep, even into moisture, may lead to less favourable positioning of the growing point and first nodal roots. This may lead to rootless corn syndrome in some cases and predisposes the seed to greater injury from herbicides. Some soil-applied herbicides require planting depths of at least 3.75 cm (1.5 in.). Coarse-textured soils that dry rapidly at the surface will also be more prone to poor root establishment in shallow plantings.

In contrast, planting deeper at 5–8 cm (2–3 in.), especially early in the planting season when soils are cold, can significantly delay emergence compared to planting depths of 3–5 cm (1.25–2 in.). Where soil temperatures are lower (i.e., early season, cool season, no-till, etc.) and when soil moisture levels are adequate, producers may want to target planting depths around 3.75 cm (1.5 in.). As the planting season progresses and as soils warm and dry, ensure that the corn seed is placed firmly into moisture. In dry soils, planting at depths of 7.5 cm (3 in.) in order to find moisture is often less risky than planting shallower and hoping for rain.

Corn Development

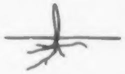
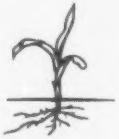
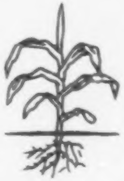
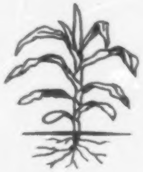
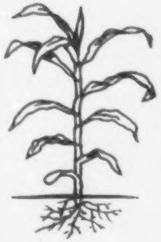
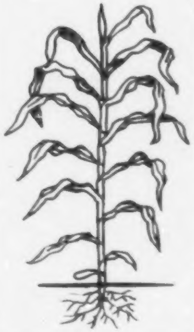
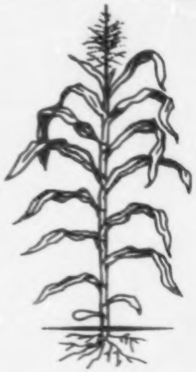
The vegetative and reproductive growth stages in corn are described in Table 3–14, *Vegetative Growth Stages in Corn*, on page 61, and Table 3–15, *Reproductive Growth Stages in Corn*, on page 62.

Uniformity of Emergence

Uniform seeding depth is a critical factor in achieving uniform emergence. Uneven emergence affects crop performance, because competition from larger, early-emerging plants reduces the yield potential of smaller, later-emerging plants (see Plate 2 on page 274). Studies indicate that yields are reduced by 5% when half the stand suffers from delayed emergence by 7 days and by 12% when half the population was delayed by 2 weeks.

Careful planter preparation may be the single biggest factor in obtaining uniform emergence. Check to see that the planter is operating level and that all discs, depth-gauging wheels and seed-firming devices are up to specifications, aligned and operating at the correct depth or pressure. Preplanting management may also play a critical role in emergence uniformity. If the field is left too uneven, if residue is bunched or if surface compaction has not been uniformly alleviated, even the most carefully prepared corn planter may not be able to deliver.

Table 3–14.
Vegetative Growth Stages in Corn

							
Stage	VE	V1	V4	V6	V8	V12	VT
Leaf Collars[1]	0	1	4	6	8	12	(varies)
Leaf Tips	1	3	7	10	11	15	—
Leaf Over	0	2	6	8	10	14	—
CHUs Required[2]	180	330	630	780	930	1,170	1,310
Target Date[3]	May 16	May 25	June 11	June 18	June 26	June 31	July 18
Notes	• Emergence. • Days to emerge most often ranges from 6–21 days. • Uniform emergence essential to high yields. • Look for poor germination caused by chafer, wireworms, seedcorn maggot, seedcorn beetle, slugs, black cutworm.	• Start of critical weed-free period. • Growing point below ground. • Ensure herbicide selection is safe for crop stage.	• Ear initiation. • Growing point below ground. • Expansion of nodal root system will soon completely replace seminal root system. • Risk from cutworm and flea beetle damage has passed.	• End of critical weed-free period. • Lower leaves (1–4) dry up, may not be visible • Growing point at or above ground; more susceptible to frost injury. • Initiated ears and tassel now visible upon plant dissection.	• Side-dressing nitrogen and inter-row cultivation beyond this point pose threat of root pruning. • Beginning rapid stem elongation. • Risk from slug damage has passed.	• Crop becomes increasingly sensitive to yield reduction by heat or drought. • Size of ear and number of potential kernels being established.	• Tassel emerges. • Pollen shed begins 2–3 days prior to silk emergence. • Pollen viability reduced by drought and high temperatures. • Scout for corn leaf aphids, corn rootworm adults and goosenecking caused by rootworm larva.

[1] Refer to the section on *Corn Leaf Stages,* on page 72, for a description of the methodologies of corn leaf counting.

[2] Approximate CHUs required to reach various stages of corn development.

[3] Estimated date to reach various stages of development based on long-term heat unit accumulations for an average 2,800-CHU region (see the data for Brucefield, Ontario, in Table 3–7, *Average Seasonal Accumulations of Crop Heat Units From Various Sites Across Ontario,* on page 54) and anticipating a May 5 planting date.

Table 3-15.
Reproductive Growth Stages in Corn

Description	Silks emerge from husks at tip of ear.	Kernels are white, filled with clear fluid and distinct from surrounding cob material.	Kernels begin to have yellow colour. Inner fluid is milky white.	Milky inner fluid becomes thicker and pasty. Outer edges of kernels become firmer. Some dents appear.	Majority of kernels are dented. Hard white layer of starch evident at top of kernel (milk line).	Hard starch layer evident from top to bottom of kernel. Black layer forms at base of kernel.
R Stage	**R1 – Silking**	**R2 – Blister**	**R3 – Milk**	**R4 – Dough**	**R5 – Dent**	**R6 – Maturity**
CHUs Required[1]	1,480	1,825	2,000	2,165	2,475	2,800
Target Date[2]	July 20	Aug. 3	Aug. 11	Aug. 18	Sept. 1	Sept. 18
Kernel Moisture	NA[3]	85%	80%	70%	55%	30%–35%
Notes	• Pollination requires 3–7 days. • Silks continue to elongate until fertilized. • Environmental stresses very detrimental to yield. • Begin scouting for ear insect pests (corn earworm, fall armyworm).	• Kernels beginning dry matter accumulation. • Relocation of nutrients from the leaves and stem to the ear begins. • Firing of lower leaves may become evident.	• Rapid grain filling period. • Good plant health, clear skies and active photosynthesis add to kernel size and test weight.	• Top of kernel begins to firm up. • Killing frost may cause yield losses of 25%–40%. • Begin to assess ear rot incidence.	• Milk line advances toward tip as crop matures. • Whole plant moistures suitable for silage harvest. • 90% of grain yield reached by one-half milk line. • Examine fields for lodging, ear drop and stalk rots – if high, consider harvesting early.	• Physiological maturity. • Kernels have achieved maximum dry weight. • Moisture loss from kernels still required for suitable threshing.

[1] Approximate CHUs required to reach various stages of corn development.

[2] Estimated date to reach various stages of development based on long-term heat unit accumulations for an average 2,800-CHU region. (See the data on Brucefield, Ontario, in Table 3-7, *Average Seasonal Accumulations of Crop Heat Units From Various Sites Across Ontario,* on page 54) and anticipating a May 5 planting date.

[3] NA – not available, kernels not formed until after pollination.

When walking corn fields keep the following in mind:

- Plants that emerge late, so that they are one or two leaves behind neighbouring plants, will most certainly lower yields relative to a uniformly emerged stand and may even lower yield below those obtained by later planted but uniformly emerged corn.
- Return on investment for planter adjustments such as installing new opener discs, levelling the planter, properly adjusting seed-firming wheels and proper seed-depth placement can be quite high.

Uniformity of Spacing

Intuitively, corn plants that are perfectly spaced down the row would seem to have a much better chance to optimize final yields. Uniformity of spacing can be measured by the occurrence of doubles or skips, or can be measured in terms of standard deviation. An absolutely perfect stand, where every plant is exactly 18 cm (7.25 in.) from its neighbour, would have a standard deviation of zero. If plants on average varied plus or minus 5 cm (2 in.) from the desired 18 cm (7.25 in.), then the standard deviation would be 5 cm (2 in.). Dr. Bob Nielsen (Purdue University, Indiana) has conducted extensive investigations into the effects of plant spacing variability on final yield. Research results indicate that every additional 2.5 cm (1 in.) of standard deviation decreases yields by 0.16 t/ha (2.5 bu/ac). Pioneer research has further supported this conclusion. Interestingly, other research has shown little decrease in yield resulting from spacing variability providing emergence was uniform and populations were identical between compared plots.

Poor planter maintenance or high planting speeds are often identified as the causes of poor within-row spacing uniformity. Research conducted in Illinois (see Table 3-16, *The Effect of Planting Speed on Spacing Standard Deviation, Population and Corn Yield*, right) illustrated that with properly maintained planters, high planting speeds and slight variations in spacing uniformity had no impact on yield.

Table 3-16.
The Effect of Planting Speed on Spacing Standard Deviation, Population and Corn Yield[1]

Planting Speed	Standard Deviation	Population	Yield
5 km/h (3 mph)	7.29 cm (2.87 in.)	67,261 plants/ha (27,231 plants/ac)	9.57 t/ha (152.5 bu/ac)
8 km/h (5 mph)	7.59 cm (2.99 in.)	67,611 plants/ha (27,373 plants/ac)	9.55 t/ha (152.2 bu/ac)
11 km/h (7 mph)	8.18 cm (3.22 in.)	66,680 plants/ha (26,996 plants/ac)	9.60 t/ha (153.1 bu/ac)

Source: E. Nafziger, University of Illinois, and H. Brown, Pioneer Hi-Bred International Inc.

[1] Average of 11 Illinois trials, 1994-96.

Row Widths

Narrow Rows

By the mid 1990s, research conducted at various locations across the northern corn belt and southern Ontario indicated that significant yield advantages could be expected from narrowing corn rows from the traditional 76-96 cm (30-38 in.) down to row widths that ranged from 38-60 cm (15-24 in.). Results showed that narrow row advantages would be greater in more northerly latitudes, compared to results coming from the mid- to southern portions of the corn belt. Ontario producers who converted to narrow row production systems at this time did so, for the most part, by converting to 50 cm (20 in.) rows and anticipated paying for planter and corn header conversions with an expected yield boost of 3%-8%. More recently, studies conducted in Ontario by the University of Guelph and by Pioneer Hi-Bred International Inc. have shown little to no yield advantage with 38 cm (15 in.) or 50 cm (20 in.) rows compared to 76 cm (30 in.) rows. The fundamental reason for moving to narrower rows is to enhance light interception. It appears that the total light interception once the canopy has fully developed is no greater in narrow rows than in wide rows. The yield advantage, if there is to be one using narrower row widths, must come from earlier canopy closure and from greater light interception in the late-June to early-July period.

In addition, research did not indicate that there were specific hybrids particularly adapted to narrow rows. High plant populations within narrow rows often boosted yields, but yields were often increased on traditional row widths as well. Yield improvements may be sporadic and the justification of equipment costs may depend on other factors such as use of the narrow row planter for other crops (i.e., edible beans), numbers of acres to be planted and costs of equipment conversions. There is the potential for increased stalk rots in narrow row systems.

Replant Decisions

There is no simple formula to aid in replant decisions, so each case must be dealt with individually. Some of the information needed to assist with a replant decision includes the original planting date, target plant population, actual population, uniformity of plant size and distribution following damage, possible replanting date and cost of replanting (seed, fungicides/insecticides, fuel, etc).

The actual plant population can be estimated by counting the number of plants in a length of row that

Table 3–17.
Expected Grain Yield Due to Various Planting Dates and Populations

	Plant Population								
Planting Date	25,000 /ha 10,000/ac	31,000/ha 12,500/ac	37,000/ha 15,000/ac	43,000/ha 17,500/ac	49,000/ha 20,000/ac	56,000/ha 22,500/ac	62,000/ha 25,000/ac	68,000/ha 27,500/ac	74,000/ha 30,000/ac
April 20	62	70	78	82	86	90	92	94	94
April 25	65	73	79	84	89	92	95	97	97
April 30	67	74	81	86	91	94	97	98	99
May 4	68	75	82	87	92	95	98	99	100
May 9	68	75	82	87	92	95	98	99	100
May 14	67	75	81	86	91	94	97	99	98
May 19	65	73	79	85	89	93	95	97	97
May 24	63	70	76	82	86	90	92	94	95
May 29	59	68	73	78	83	86	89	90	91
June 3	54	62	68	74	78	82	84	86	86
June 8	49	56	63	68	73	76	79	80	81

Adapted from University of Illinois data. E.D. Nafziger. 1994. *Journal of Production Agriculture.* Original data from Illinois was shifted 10 days later to reflect optimal planting dates in Ontario.

Example: A field is planted on May 4 with an expected plant population of 62,000 plants/ha (25,000 plants/ac). By the end of the month, the stand is reduced to 31,000 plants/ha (12,500 plants/ac) but uniform in size and plant distribution. The table would suggest that the expected yield for a final plant stand of 31,000 planted on May 4 would be 75% (a 50% reduction from the targeted population). By planting on May 29 at the same population (62,000), a yield of 89% can be expected. In this case, the cost of replanting may be recovered and therefore justified. If your planting date or plant stands don't match the listed values, you must interpolate.

is equal to 1/1,000 of an acre (see Table 1–2, *Length of Row Required for a Thousandth of an Acre at Various Row Widths*, on page 3). This should be replicated at least 5 times per 10 ha (25 ac) in separate parts of the field. Calculate the average of these samples and then multiply the average by 1,000.

It is important when taking stand counts to observe the uniformity, plant size and distribution of the plants in the rows. How do the stand, plant size and distribution vary? Yields can be reduced by 2% if the stand has several 30–90-cm (12–36 in.) gaps. If the gaps are larger, 1.25–2 m (4–6 ft), expect a 5–6% reduction in yield when compared to a uniform stand. The more numerous and longer the gaps are between plants within the row, the greater the yield reduction.

Table 3–17, *Expected Grain Yield Due to Various Planting Dates and Populations*, above, can be used as a starting point in the decision process. It shows the effect of planting date and plant population on final grain yield. Yields are based on stands that are normal in terms of uniformity of plant size and distribution. Grain yields for varying dates and populations are expressed as a percentage of the yield obtained at the optimum planting date and population (64,200–76,200 plants/ha or 26,000–30,000 plants/ac). Results will vary depending on location, environmental conditions, hybrid and other factors.

The availability of early maturing hybrids with good yield potential and the cost of replanting will play a factor in the replant decision. Consider whether the herbicide program allows for a switch to soybeans; if not, do corn herbicides need to be reapplied? What is the condition and health of the remaining crop? Before replanting, determine whether the conditions that caused the problem in the first place still exist (soil conditions, disease, insects, herbicide injury). If an insect or disease problem was the culprit, the cost of an insecticide and/or fungicide treatment must also be factored in.

Fertilizers for Corn

Nitrogen

Corn responds well to nitrogen, so adequate availability of nitrogen is critical to profitable corn production. Excess nitrogen, however, adds unnecessary expense to corn production, as well as increases the risk of nitrate movement to the groundwater.

Nitrogen deficiency shows up on the lower leaves of a plant first, manifested as yellowing beginning at the tip of the leaf and proceeding down the midrib (see Plate 1 on page 273 and Plate 5 on page 274). Eventually, the yellow areas will turn brown and die.

In young plants, however, yield loss will occur long before nitrogen deficiency symptoms appear, so yellowing is not a reliable indicator of the need for nitrogen fertilizers.

Two methods can be used to determine optimum nitrogen rates: the nitrate-nitrogen soil test or general recommendations based on expected yield and location, adjusted for legumes, manure or other sources of organic nitrogen.

> It is common to see symptoms of nitrogen deficiency in the lower leaves as the plants near maturity, even when there is adequate nitrogen for optimum yield.

Nitrate-Nitrogen Soil Test

Soils can vary greatly in their ability to supply nitrogen. The amount of nitrate-nitrogen present in the soil at planting time can be a useful indicator of a soil's capacity to supply nitrogen. Use of the soil test for nitrate-nitrogen should result in a more efficient and profitable use of nitrogen as well as a reduction in the risk of nitrate movement into the groundwater.

Time of Sampling

The nitrogen recommendations based on the soil test for nitrate-nitrogen were developed using samples that were taken within 5 days of planting (before or after). Often, this is not a convenient time for sampling, and seasonal differences in weather can dramatically change the soil tests at this time of year (refer to the section *Where Caution Is Required*, on page 65). Alternatively, sampling when the corn is 15–30 cm (6–12 in.) tall, before applying side-dress nitrogen, has increased in popularity. This is referred to as the pre-side-dress nitrogen test (PSNT).

By delaying sampling past the busy planting season, the PSNT allows more time for sampling and receiving results from the laboratory. More importantly, considerable evidence indicates that nitrogen recommendations based on this later sampling time are superior to those based on a planting time sample. This is particularily true when there are organic sources of nitrogen such as manure or legumes in the cropping system. PSNT samples taken in June detect nitrate that has mineralized from these organic sources and will more accurately reflect total available nitrogen and fertilizer nitrogen requirements.

Taking the Sample

As nitrates are more mobile than either phosphorus or potassium, a separate, deeper, soil sample must be taken for the nitrate-nitrogen test. The soil should be sampled to a depth of 30 cm (12 in.). It is important that all cores in a field be taken to the same depth and that the sampling depth be included with the information sent with the sample to the lab.

To ensure that the sample is representative of the field, use a sampling pattern similar to that recommended for the standard soil test in the section *Soil Sampling*, on page 29. Because variations in soil nitrate content can have such a large impact on nitrogen fertilizer recommendations, it may be worthwhile to sample more intensively for nitrate than for phosphorus or potassium. Sample areas with differences in past management separately, and knolls separately from depressions. Areas of a field with distinctly different soil types should also be sampled separately.

Handling the Sample

Cores should be placed in a clean plastic pail, crushed by hand and well mixed. Take about 500 gm of soil (1 lb) from the pail and place it in a clean plastic bag or soil sample box.

Microbial action in the sample can change its nitrate content quickly if it is not handled properly. Samples should be chilled or frozen as soon as possible. For shipping, samples should be packed with insulating material to keep them cool and sent by courier to ensure quick delivery to the lab.

Samples can also be air-dried. Spread the sample in a thin layer on a clean plastic sheet, breaking up any large lumps in the process. It should be dry in 1–2 days, and can be shipped to the labs without any extra precautions. Do not dry the samples in a warm oven, as it can affect the nitrate content.

Where Caution Is Required

Sometimes the fertilizer recommendations based on the nitrate-nitrogen soil test should be modified.

The nitrogen in manure or legumes applied or plowed down just before sampling will not have converted into nitrates and will not be detected by the soil test. Information will be provided with the test results on how to make appropriate adjustments.

The nitrate-nitrogen soil test has not been adequately evaluated for:

- legumes or manure plowed down in the late summer or fall
- legumes in a no-till system

**Table 3–18.
Nitrogen Recommendations
Based on Nitrate-Nitrogen**

Spring Nitrate Nitrogen[1] in Top 30 cm (1 ft)	Pre-Side-Dress Nitrate Nitrogen[2] in Top 30 cm (1 ft)	Actual Nitrogen Recommended	
(ppm)	(ppm)	(kg/ha)	(lb/ac)
1	1	211	189
2	3	199	178
3	4	186	166
4	5	173	155
5	7	161	144
6	8	148	132
7	9	135	121
8	10	123	110
9	12	110	98
10	13	97	87
11	14	85	76
12	16	72	64
13	17	59	53
14	18	47	42
15	20	34	30
16	21	21	19
17	22	9	8
18	23	0	0

Conversion Factors

To convert soil test results from kg/ha to ppm for a 30-cm (12-in.) sample, divide kg/ha by 4. For example, if the nitrate-nitrogen concentration of a sample taken from the top 30 cm (12 in.) of soil is 32 kg/ha, the nitrate nitrogen is 32 kg/ha ÷ 4 = 8 ppm.

[1] Spring nitrate-nitrogen refers to samples taken within 5 days of planting (either before or after).

[2] Pre-side-dress nitrate-nitrogen refers to samples taken when the corn is 15–30 cm (6–12 in.) tall (usually within the first 2 weeks of June).

- soil samples taken prior to planting before the soil has warmed up significantly (i.e., in mid- to late April)

The nitrate-nitrogen soil test should be used with caution in these circumstances.

Table 3–18, *Nitrogen Recommendations Based on Nitrate-Nitrogen*, above, shows the recommended application rates of nitrogen for different levels of soil nitrate-nitrogen for samples taken to a depth of 30 cm (12 in.) when the nitrogen/corn price ratio is 5. (For an explanation of the price ratio, see the section *Nitrogen/Corn Price Ratio*, right.) If the price ratio is increased to 7 (i.e., the price of nitrogen fertilizer has increased or the price of corn has decreased), the recommended rates should be reduced 20 kg/ha from the rates in this table. If the price ratio drops to 3, the rates should be increased by 30 kg/ha.

Rates should be adjusted downward if the preceding crop was a legume sod (see Table 2–15, *Adjustment of Nitrogen Requirement Where Crops Containing Legumes Are Plowed Down*, on page 36). If manure was applied, see Table 2–16, *Average Amounts of Dry Matter, Nitrogen and Available Phosphate and Potash for Different Types of Organic Nutrient Sources*, on page 37.

Laboratories

See Appendix B, *Accredited Soil-Testing Laboratories in Ontario*, on page 257, for a list of laboratories that are accredited to analyze soil samples for nitrate-nitrogen.

Nitrogen/Corn Price Ratio

The most profitable rate of nitrogen application is also affected by the relative prices of corn and nitrogen, which can be expressed as a nitrogen/corn ratio. This ratio is calculated by dividing the cost of nitrogen, in dollars per kilogram of actual N, by the expected selling price of grain corn, in dollars per kilogram.

a) To determine the cost per kg of actual nitrogen, divide the cost per tonne of fertilizer material by 10 times the percentage of nitrogen in the fertilizer. Application costs should be included.

$$\text{Cost of N/kg} = \frac{\text{Cost of Nitrogen Fertilizer per Tonne}}{10 \times (\text{\% Nitrogen in Fertilizer})}$$

b) To determine the selling price per kg of corn, divide the price per tonne by 1,000. Include any anticipated payments from stabilization or market revenue programs.

c) To determine the nitrogen/corn price ratio, divide the cost of N per kg by the selling price of grain corn per kg.

$$\text{Nitrogen/Corn Ratio} = \frac{\text{Cost of N/kg}}{\text{Price of Corn/kg}}$$

The recommendations in Table 3–18, *Nitrogen Recommendations Based on Nitrate-Nitrogen*, left, and Table 3–19, *General Recommended Nitrogen Rates for Corn*, on page 67, are based on a nitrogen/corn price ratio of 5 (e.g., a nitrogen cost of \$0.65/kg of actual nitrogen and a corn price of \$0.13/kg or \$130/tonne).

General Recommendations

In the absence of a soil test for nitrate-nitrogen, Table 3–19, on page 67, can be used to determine an average recommendation for nitrogen for various regions of Ontario based on the expected yield and what is expected from a field in a normal year, based

Table 3-19. General Recommended Nitrogen Rates for Corn

	Expected Grain Yield (t/ha)					
	6	7	8	9	10	11
Region	Most Profitable Nitrogen Rate (kg/ha of N)					
Eastern	90	110	130	155	175	200
Western and Central	100	110	120	125	135	140
Southwestern preplant	160	75	185	190	200	210
Southwestern side-dressed	140	145	150	155	160	165

100 kg/ha = 90 lb/ac 1 t/ha = 16 bu/ac

Table 3-20. Nitrogen Recommendations for Corn Grown in Rotation

	Reduction in N Required From Table 3-19 (kg/ha of N)	
Rotation	Southwestern Ontario	Western, Central and Eastern Ontario
Corn following soybeans or field beans	15	30
Corn following silage corn	0	10
Corn following cereals (straw removed)	0	10

on previous experience. Nitrogen rates can be reduced following some crops (see Table 3-20, *Nitrogen Recommendations for Corn Grown in Rotation*, right). Fertilizer rates should also be adjusted for legumes plowed down (see Table 2-15, *Adjustment of Nitrogen Requirement Where Crops Containing Legumes Are Plowed Down*, on page 36) and manure applied (see Table 2-16, *Average Amounts of Dry Matter, Nitrogen and Available Phosphate and Potash for Different Types of Organic Nutrient Sources*, on page 37).

Sample Calculation

If the expected yield of grain corn in a field in western Ontario is 7 t/ha (112 bu/ac), the nitrogen recommendation would be 110 kg/ha. (See Table 3-19, above.) If the soil tests are 11 for phosphorus and 110 for potassium, the phosphate requirement would be 50 kg/ha and the potash requirement 30 kg/ha. (See Table 3-21, *Phosphate and Potash Recommendations for Corn Based on OMAFRA-Accredited Soil Tests*, on page 68.) The phosphate could be supplied by 160 kg/ha of 8-32-16 (50 x 100/32 = 160). This would also supply 12 kg of nitrogen/ha and 25 kg of potash/ha. The remaining 98 kg of nitrogen/ha could be supplied by 120 kg of anhydrous ammonia/ha (98 x 100/82 = 120).

Nitrogen Application

The major portion of the nitrogen should be applied in the spring, either preplant, pre-emergence or side-dressed before the corn is 30 cm (12 in.) high. Fall application is not recommended because of the potential for high losses.

A portion of the nitrogen may be applied in a band at planting. Take care that safe rates of fertilizer near the seed are not exceeded. Where it is desirable to apply high rates of nitrogen at planting, it should be placed in a separate band from the high phosphate starter at a distance from the seed row greater than 10 cm (4 in.).

In southwestern Ontario, side-dressed applications have shown a slight yield advantage over preplant applications and anhydrous ammonia has produced 3%-5% higher yields than urea or ammonium nitrate. Throughout the rest of the province, there has been no yield advantage for side-dressed applications, and no yield differences have been found comparing the various nitrogen materials.

Solid forms of nitrogen or urea-ammonium nitrate solutions (UAN) may be applied to the soil surface without incorporation. However, urea or UAN applied on crop residues should be incorporated into the soil immediately. Urea or UAN that is left on the surface can lose a significant amount of nitrogen to the air through ammonia volatilization. Under dry conditions, the effectiveness of all forms of nitrogen may be improved by incorporation. If UAN solutions contact leaves, burning and yield reductions may occur.

Anhydrous ammonia, applied with conventional equipment, should be placed a minimum of 15 cm (6 in.) deep in the soil. For preplant applications, applicator outlets should be no more than 50 cm (20 in.) apart. For wider spacings, a 4-day waiting period before planting is recommended to avoid damage to seedlings.

When appropriate equipment is used, ammonia may be applied with a cultivator or disc, a minimum of 10 cm (4 in.) deep with the ammonia outlets spaced no more than 50 cm (20 in.) apart.

Phosphate and Potash

Adequate phosphorus and potassium are necessary for optimum corn growth and yield, although the response to these nutrients is not as evident as with nitrogen. Phosphorus deficiency does not show any obvious symptoms, although phosphorus-deficient plants will be stunted and may have a darker green or purplish colour (see Plate 1 on page 273). Purple leaves may also be an indication of cool weather stress or root injury (see Plate 3 on page 274). Potas-

Table 3-21.
Phosphate and Potash Recommendations for Corn Based on OMAFRA-Accredited Soil Tests

Sodium Bicarbonate Phosphorus Soil Test (ppm)	Rating	Phosphate (P_2O_5)[1] Required kg/ha	Ammonium Acetate Potassium Soil Test (ppm)	Rating	Potash (K_2O)[1] Required kg/ha
0-3	LOW	110	0-15	LOW	170
4-5		100	16-30		160
6-7		90	31-45		140
8-9		70	46-60		110
10-12	MEDIUM	50	61-80	MEDIUM	80
13-15		20	81-100		50
16-20		20	101-120		30
21-30	HIGH	20	121-150	HIGH	0
31-60	VERY HIGH	0	151-250	VERY HIGH	0
61+	EXCESSIVE[2]	0	251+	EXCESSIVE[2]	0

100 kg/ha = 90 lb/ac

[1] Where manure is applied, reduce fertilizer applications according to the amount and quality of manure (See Table 2-16, *Average Amounts of Dry Matter, Nitrogen and Available Phosphate and Potash for Different Types of Organic Nutrient Sources*, on page 37.)

[2] When the soil test rating for a nutrient is "Excessive," application of this nutrient in fertilizer or manure may reduce crop yield or quality. For example, phosphate applications may induce zinc deficiency on soils low in zinc and may increase the risk of water pollution. Potash application on soils low in magnesium may induce magnesium deficiency.

sium deficiency symptoms appear on the lower leaves of the plant first, showing as yellowing and browning beginning at the tip and proceeding back along the outside margin of the leaf (see Plate 1 on page 273 and Plate 4 on page 274). Both of these nutrients will exhibit "hidden hunger," where yields are reduced by a deficiency of one or both of these nutrients even though no deficiency symptoms are visible.

Phosphate and potash recommendations for corn are presented in Table 3-21, *Phosphate and Potash Recommendations for Corn Based on OMAFRA-Accredited Soil Tests*, above.

For information on the use of this table or if you do not have an OMAFRA-accredited soil test, see the section *Fertilizer Recommendations*, on page 31.

Where soil tests indicate that large amounts of phosphorus and potassium are required, the major portion may be broadcast and incorporated in the fall or spring. However, where soil tests show a requirement for these nutrients, a fertilizer containing nitrogen (preferably in the ammonium form) and phosphorus, or nitrogen, phosphorus and potassium should be applied as a starter at planting. All of the phosphorus and some of the potassium may be applied in a band 5 cm (2 in.) to the side and 5 cm (2 in.) below the seed (see Table 2-30, *Maximum Safe Rates of Nutrients*, on page 47).

Seed Placed Fertilizer

Field trials over several years have shown that an application of 10-15 kg P_2O_5/ha (9-13 lb P_2O_5/ac) directly with the seed of corn will give greater yield increases than 20 kg P_2O_5/ha (18 lb P_2O_5/ac) in a side band. At phosphorus soil tests of 13 to 45, this "with-seed" application is more likely to give a profitable response than a side-band application. At soil tests below 13, application of 10-15 kg P_2O_5/ha (9-13 lb P_2O_5/ac) with the seed may also be profitable but cannot replace the requirement for additional phosphorus in the side band or broadcast.

Fertilizers to be applied with the seed should contain nitrogen (in the ammonium form), must be low in salt and must not contain either urea or diammonium phosphate (see Table 2-30, on page 47). They must also be distributed uniformly to avoid toxicity to the germinating seed. Application of more than 15 kg P_2O_5/ha (13 lb P_2O_5/ac) with the seed (in 75-cm (30-in.) wide rows) is not recommended.

Maximum Safe Rates of Fertilizer

Applying too much fertilizer to corn may result in crop injury, either from excessive salts or ammonia. The more concentrated the fertilizer, and the closer it is to the seed, the greater the risk of crop injury and the lower the safe rate. Maximum safe rates are given in Table 2-30, on page 47. Note that slight reductions in crop growth and yield are possible with these application rates under adverse weather conditions.

Secondary and Micronutrients

Magnesium

Magnesium is plentiful in most soils in Ontario, but a deficiency can occur on acid, sandy soils. The symptoms appear first as yellow striping of the lower leaves (see Plate 1 on page 273 and Plate 6 on page 274). As the deficiency worsens, the upper leaves may become striped while the lower leaves turn reddish-purple.

All soil samples analyzed under the OMAFRA-accredited soil testing program are tested for magnesium. This test is a reliable guide for determining magnesium requirements.

Dolomitic lime is an excellent source of magnesium. Where limestone is required to correct soil acidity, dolomitic lime should be used whenever the magnesium test is less than 100 ppm. For further information, see the OMAFRA Factsheet, *Soil Acidity and Liming*, Order No. 91-086, or visit the Web site at www.gov.on.ca/OMAFRA/english/crops.

Few soils that do not need lime will require magnesium. Magnesium application is recommended only if the magnesium test is under 20 ppm. On these soils, magnesium can be supplied either by magnesium sulphate or, if potassium is also required, by sulphate of potash magnesia. Apply 30 kg of water-soluble magnesium/ ha (27 lb/ac).

Over-application of potassium can induce magnesium deficiency. For this reason, it is important to monitor soil potassium levels closely and restrict potash application rates to those recommended by the OMAFRA-accredited soil test.

Sulphur

Sulphur deficiency has not been observed in corn in Ontario. The corn-growing areas of the province receive adequate sulphur as acid precipitation.

Zinc

Zinc deficiency occurs on corn in Ontario. Visible symptoms on the leaves (see Plate 7 on page 274) are the best indications of deficiency, but soil tests are also useful. Zinc deficiency usually appears as a broad white band near the base of the younger leaves on a corn plant. In severe deficiencies, the entire leaf in the whorl will be white (known as "white-bud"). Response to zinc should not be expected unless deficiency symptoms are quite marked.

When zinc is required, it may be applied to the soil mixed in the fertilizer at rates supplying 4–14 kg/ha (3.5–12.5 lb/ac). The higher rate should be sufficient for up to 3 years. Not more than 4 kg/ha should be banded at planting. Zinc may be applied as a foliar spray at rates supplying 60 g/100 L (0.6 lb/100 gal). A wetting agent should be added. Spray to leaf wetness. For further information, see the section on *Micronutrient Fertilizers*, on page 34.

Manganese

Manganese deficiency in corn is rare, although there have been a few occurrences reported on muck soils with high pH in southwestern Ontario. Corn is much more tolerant of low soil manganese levels than soybeans or cereals. Manganese deficiency in corn appears as an olive-green discolouration of the leaves, occasionally with faint striping. Foliar application of manganese is the most effective way to correct a deficiency.

Correct the deficiency as soon as detected by spraying the foliage with 2 kg of actual manganese/ha from manganese sulphate (8 kg of manganese sulphate/ ha) in 200 L of water. A "spreader-sticker" in the spray is recommended. If the deficiency is severe, a second spray may be beneficial. When applying micronutrients, take care to first clean out the spray tank of a sprayer that has been used to apply herbicides.

Other Micronutrients

Other micronutrients are not likely to be deficient in corn in Ontario. Some micronutrients, such as boron, can be toxic if applied to corn, particularly if applied in a band or in the starter/pop-up fertilizer.

Plant Analysis

The most appropriate growth stage for sampling corn for plant analysis changes for different nutrients. For most nutrients, sampling the mid-third of the ear leaf at silking is most appropriate. Refer to Table 3–22, *Interpretation of Plant Analysis for Corn*, on page 70. For phosphorus and zinc, however, sampling the whole plant when 5–6 leaves are visible is more appropriate.

Plants suspected of having nutrient deficiency should be sampled as soon as the problem appears. For plants with six leaves or less, sample the total above-ground plant. From seven leaves to silking, sample the youngest fully developed leaf. Take separate samples from areas with and without symptoms for comparison. For sampling at times other than silking, samples should be taken from both deficient and healthy areas of the field for comparative purposes.

Table 3-22.
Interpretation of Plant Analysis for Corn

Nutrient	Units	Critical Concentration[1]	Maximum Normal Concentration[2]
Seedling Corn (5-6 leaves)			
Phosphorus	%	0.35	0.70
Zinc	ppm	20.0	70.0
Silking (mid-third of leaf opposite ear)			
Nitrogen (N)	%	2.5	3.5
Phosphorus (P)	%	0.28	0.50
Potassium (K)	%	1.2	2.5
Calcium (Ca)	%	—	1.5
Magnesium (Mg)	%	0.10	0.60
Sulphur (S)	%	0.14	—
Boron (B)	ppm	2.0	25.0
Copper (Cu)	ppm	2.0	20.0
Manganese (Mn)	ppm	15.0	150.0
Zinc (Zn)	ppm	20.0	70.0

[1] Yield loss due to nutrients deficiency is expected with nutrient concentrations at or below the "critical" concentration.

[2] Maximum normal concentrations are more than adequate but do not necessarily cause toxicities.

A soil sample should be taken from the same area and at the same time as a plant sample.

For more information, see the section *Plant Analysis*, on page 30.

Foliar Fertilization

The foliar application of nutrients to corn has not proven effective in most instances. The rates of nutrients required cannot be applied as a foliar spray without causing damage to the leaf, unless numerous small applications are made (see Plate 8 on page 275). The exception is correction of some of the micronutrient deficiencies, but even in this case it is often more economical to apply the nutrient to the soil.

Corn Harvesting

Physiological maturity (black layering) occurs when the grain moisture content is approximately 31%-33% moisture. After this stage there is no dry matter added to the corn kernel. Harvesting grain corn at moisture contents above 28% often results in significant damage to the grain and makes it more difficult to market commercially. High quality food grade markets may require harvest moistures to be as low as 20%-22%.

Growers must weigh the benefits of delaying harvests to lower drying cost and improve sample quality versus the increased risks that come from higher levels of stalk lodging, ear drop and wet weather. The need to adjust harvesting dates forward to prevent harvest losses is determined by scouting fields and checking for stalk quality. When stalk quality is poor, the next significant wind or rainstorm may increase harvest losses dramatically. Efficient header performance is also important when harvesting corn of low stalk strength. Keep header speed in-step with ground speed to improve stalk flow down through the stripper plates and snapping rolls. These may also need to be adjusted to be brought closer together.

Corn damage to grain quality by the combine can result from any of the following:

a) cylinder speed too high
b) concave clearance too narrow
c) too many concave filler bars
d) concave and cylinder not parallel

Ontario experience with harvesting corn that has been frozen prior to maturity generally indicates that running the cylinder speed as slow as possible is the key to maintaining quality.

To assess harvest losses from your combine, consider the following guidelines: 22 kernels per square metre (2 kernels per square foot) represent approximately 0.06 t/ha (1 bu/ac) in losses and one average-sized ear in 1/100 ac represents 0.06 t/ha in lost yield. If combine losses exceed 0.16 t/ha (2.5 bu/acre), adjustments are warranted.

Harvesting and Storing Corn Silage

For a full discussion, see the section *Haylage and Corn Silage*, on page 156.

Corn Storage

Drying and Storing Corn

The three basic general types of grain dryers used on the farm are:

- in-bin
- batch
- continuous flow

No single drying system is superior to all others in every respect. System selection is dependent on desired features including drying capacity, grain quality, fuel/drying efficiency (BTUs per kilogram of water removed), convenience, manpower required to run

Table 3–23.
Maximum Recommended Air Temperatures (°C and °F) for Drying Corn of Various End Uses

End Use	Maximum Temperature (°C)	Maximum Temperature (°F)
Seed corn	45	113
Starch milling	70	158
Industrial uses, non-ruminant feed	90	194
Cattle feed	120	248

the dryer, ability to dry a variety of crops, maintenance required and capital cost.

All dryers move air past the grain to evaporate moisture within the kernel and carry the water vapour away. Heat is added to this drying air to reduce its relative humidity, thereby increasing its ability to pick up moisture. Wet grain can be dried at higher temperatures since it will be cooled as the moisture evaporates from the kernels. As the grain dries, it will approach the temperature of the drying air. The longer that grain kernels are in contact with this heated air, the drier and hotter the kernels will get.

Drying Corn With Heated and Unheated Air

Corn dries as the moisture from the inside of the kernels is evaporated from the kernel surface. Most of the moisture inside the kernel exits through the tip end of the kernels. The first few points of moisture can be easily removed using relatively little energy. Further moisture must be removed from deep within the corn kernels. As the outside layers of the kernel dry, the moisture must migrate out from the moist centre. This moisture does not move to the surface as quickly as it is being evaporated from the surface of the kernel by the drying air. This results in higher energy requirements to remove the last few percentage points of moisture.

Drying Temperatures

A range of drying temperatures can be used to dry corn but should not exceed the maximum recommended air temperatures displayed in Table 3–23, *Maximum Recommended Air Temperatures (°C and °F) for Drying Corn of Various End Uses*, above. The maximum recommended drying temperature depends on several factors including final end use of the grain, initial moisture content of the grain, type of grain and type of dryer.

Viability is destroyed when the actual grain temperature exceeds approximately 50°C (122°F). Reduction in nutritional value occurs when grain temperature reaches 90°C to 100°C (194°F to 212°F).

Kernel Quality

Taking corn hot out of the dryer, allowing it to steep for a time and then aerating the corn with a minimum of 6.5 L/sec/m^3 (.5 CFM/bu) airflow will reduce stress cracking.

Stress cracking and physical kernel damage are influenced by the speed of moisture removal and also by maximum kernel temperature, coupled with the rate of cooling after drying.

In addition to maintaining grain quality, using this system of dry-aeration or cool-aeration can increase the throughput of the drying system.

Natural-Air Drying

Natural-air drying of corn is possible in most parts of southern Ontario. This method of drying corn is well suited for livestock operations to produce high-quality corn that is free of stress cracks. Good management of a natural-air drying system is critical to success.

Minimum Requirements for Natural-Air Drying

- Full aeration floor in the bin
- Level grain surface across the whole bin
- Minimum airflow of 26 L/sec/m^3 (2 CFM/bu), preferably more
- Corn 25% moisture content or less
- Clean corn with no cob pieces or fines
- Accurate moisture reading of the corn in the bin
- Accurate outside air temperature and relative humidity measurement
- An understanding of corn equilibrium moisture content
- Coring the bin (auger out some grain) after filling. The best way is to remove a couple of loads from the bin. This establishes the flow funnel and removes the highest concentration of fines from the centre of the bin. These loads should be cleaned before placing them back into the bin, otherwise the unclean loads will make the resistance to airflow less than if the bin had not been cored.
- An on/off switch for the fan

When to Run the Fan

Fan operation in a natural-air corn-drying bin is slightly different than for other air-dried crops. Once there is sufficient corn in the bin to hold the perforated floor down, the fan can be turned on. The fan should remain on continuously for the first 3 weeks after the bin has been filled or the first drying front has come through the top of the bin.

The first drying front will be evident when there is a noticeable drop in the moisture content of the corn at the top of the bin. Before this drying front passes through, the corn at the top of the bin will remain at harvest moisture levels and may even increase slightly compared with the corn drying further down. If the fan is shut off for an extended period of time at the start of the drying process, there is a risk that the drying front moving through the corn may stall and will not move upwards once the fan is turned on again. This will result in spoilage occurring above the drying front.

Rain or shine, the fan should not be turned off until the first drying front has passed through the whole bin.

Once the first drying front passes through the top of the bin, begin to manage the fan operation, using the equilibrium moisture chart for corn. (See the section *Equilibrium Moisture Content*, below). The fan should be run any time the outside conditions will still allow drying to occur, even with the wettest corn. At times, this procedure may add some moisture to the corn at the bottom of the bin and will actually dehumidify the air so it can do more drying up further in the pile.

The corn may not reach the desired moisture content before freezing weather arrives. Trying to accomplish natural-air drying in below-freezing temperatures is very slow and inefficient. The last few points of moisture may have to be taken out in early spring. Some producers never finish drying the corn any further after winter, since it processes and stores well as feed at the higher moisture levels.

Humidistats are available that will activate the fan at preset humidity levels. The operator can adjust the relative humidity level at which the fan is activated. Bins with stirrators will have fairly uniform moisture levels throughout the whole bin as a result of the mixing that has occurred.

Corn at moisture levels greater than 25% can also be dried in a natural-air bin. This works by only partially filling your natural-air bin, resulting in an airflow of 52–78 L/sec/m^3 (4–6 CFM/bu). Producers who need corn for feed in late September can harvest headlands and put this in the bin. The warm temperatures in late September, combined with higher CFM/bu airflow enable this corn to be dried in a couple of weeks.

Equilibrium Moisture Content

Researchers have developed equilibrium moisture content tables that allow you to predict the final moisture content of corn when exposed to air at a certain temperature and relative humidity (see Table 3–24, *Equilibrium Moisture Content (% Wet Basis) for Corn Exposed to Air at Various Temperatures and Humidity*, right). For example, to determine the equilibrium moisture content of corn exposed to outside air at 10°C (50°F) and 70% relative humidity, find the point at which the 10°C (50°F) line and the 70% relative humidity line intersect. This point will be the equilibrium moisture content for corn at the outside air conditions stated.

Table 3–24.
Equilibrium Moisture Content (% Wet Basis)
for Corn Exposed to Air at
Various Temperatures and Humidity

Temperature °C (°F)	Relative Humidity %				
	50	60	70	80	90
0 (32)	13.7	15.1	16.6	18.4	21.3
5 (41)	13.1	14.4	15.9	17.8	20.7
10 (50)	12.5	13.8	15.4	17.3	20.2
15 (59)	11.9	13.3	14.9	16.8	19.8
20 (68)	11.5	12.8	14.4	16.4	19.4
25 (77)	11.0	12.4	14.0	16.0	19.0

Weed Control

The critical period to control weeds in corn is the 2- to 8-leaf over stage (3 to 10 leaf tips or V1 to V6).

Critical Period for Weed Control

Season-long weed control is not necessary to protect yield. Maintaining good weed control during the period from the 2- to 8-leaf stage has been shown in research to keep the yield loss due to weeds to less than 5%. Weeds germinating later have minimum impact on crop yields and result in relatively low production of weed seeds. The herbicide label indicates the growth stage of the weeds when optimum control can be obtained. The timing of weed control should optimize the critical period for the crop and the optimum growth stage of the weed. Weed control should occur within the labelled timing for the crop but should be timed primarily on the weed leaf stage and density. The critical period for weed control will vary within the 2- to 8-leaf stage depending on factors such as soil type, soil moisture, precipitation, weed species and density, growing conditions, etc. The timing is earlier within the window for conditions that result in greater stress potential to the crop. For example, weed control in corn grown on coarse-textured soils with high weed densities and low soil moisture will require weed control to occur at an earlier stage within the critical weed-free period.

Corn Leaf Stages

Counting the leaves on a corn plant sounds like an easy task, but there are a few complications that can cause one to miscount. It is important when reading

Table 3-25.
Comparative Growth Stages

Leaf Over	Collars	Leaf Tips	Standing Height (cm)	Leaf Extended (cm)
2	1	3	5–6	5–11
4	3	5–6	9–17	16–25
6	4–5	7–8	18–33	29–46
8	5–6	9–10	36–54	54–77
10	8	12	58–85	86–112
12	10	14–15	99–114	121–149

Source: *Guide to Weed Control*, Publication 75, OMAFRA

pesticide labels or other information to know which leaf counting method is being referred to.

There are several methods of counting leaves:

- One method counts all leaves including any leaf tip that has emerged from the whorl at the top of the plant (leaf tip method).
- The second method only counts those leaves that are fully emerged and are arched over with the next leaf visible in the whorl but standing straight up (leaf over method).
- The leaf collar method used extensively in the U.S. refers to the leaf collar being visible, where the leaf collar is the light green to whitish band that separates the leaf blade from the leaf sheath, which wraps around the stem. The corn stages for corn are referred to as V1, V2, V3, etc., where the V3 stage is a plant with three collars showing.

In OMAFRA Publication 75, the *Guide to Weed Control*, leaves are counted that have emerged from the whorl and are starting to arch over (leaf over method). This normally occurs when leaves are about 50% emerged. Most herbicide labels refer to this method of leaf counting, but check the label or contact the product representative to confirm.

Another complication with leaf counting is that it starts with the bottom leaf known as the first leaf. The first leaf is shorter than other leaves and has a round leaf tip. As the plant grows, the bottom leaves start to die and drop to the ground. A 10-leaf corn plant may have one to three leaves that have died, and these dead leaves may or may not be visible. Care must be taken to account for them as well in leaf counts.

Hint: Start counting from the bottom leaf, and check that the first leaf visible is the one with the rounded leaf tip.

It takes approximately 75 to 80 Crop Heat Units to produce each corn leaf. Therefore at temperatures of 30°C (86°F) during the day, and 20°C (68°F) at night, there is one new leaf every 2 to 3 days; and at 20°C (68°F) during the day, and 10°C at night, one new leaf appears every 5 to 6 days.

Some herbicide labels may use plant height to indicate crop or weed growth stage. Actual plant height may vary due to genetics and the weather or other stesses of the season. Table 3-25, *Comparative Growth Stages*, left, gives some comparative heights for each leaf stage, but plants may vary from the stage in the table. The standing height is measured from the ground surface to the top of the plant as it stands. "Leaf extended" refers to the height of the plant with the leaves pulled up to their full height.

Crop Losses Due to Weeds

Certain weeds are more competitive than others. Table 3-26, *Percent Corn Yield Loss Due to Weeds at Known Populations*, on page 74, shows some comparative yield losses due to weeds, assuming that the weeds emerge with the crop. Crop scouting is essential to determine the weed species and weed populations present in the field. Consider the competitiveness of weed species when deciding whether to treat escapes. Effects on crop quality and harvest procedures also need to be considered. These estimates are based on normal weather conditions and adequate soil moisture. Yield losses may increase under drier soil conditions and be variable under conditions of plant stress.

Mechanical Weed Control

Small annual weed seedlings can be partially controlled by blind harrowing, before the corn has emerged, with a set of light harrows operating at a shallow depth or by using a weeder harrow (with L-shaped flexible tines) when the crop is 5–10 cm tall. High speed (10 km/h or 6.2 mph), shallow (2.5–3 cm) cultivation with the rotary hoe when corn is 7–8 cm (2¾–3 3/16 in.) high will help control small weed seedlings. These techniques will not reduce herbicide action and may in some years enhance chemical weed control. Inter-row cultivation can be used to complement other weed control measures. Row cultivation is most effective when weeds are small. Cultivation should be shallow to reduce germination of new weed seeds, soil moisture loss and corn root injury. Inter-row cultivation may be required when weeds escape a herbicide treatment. Weeds should be considered as escapes when they are 5–7 cm (2–2¾ in.) high.

Band treatment of chemical over the row will reduce cost by half to two-thirds, depending on the row spacing and the width of the band. Shallow inter-row cul-

Table 3-26.
Percent Corn Yield Loss Due to Weeds at Known Populations
Crop losses assume all weeds emerge with the crop.

	Corn (% loss)		
	Weedy Plants/m^2		
	1/m^2	5/m^2	25/m^2
Annual broadleaves			
Giant ragweed	13	36	56
Lamb's-quarters	12	35	56
Pigweed	11	34	55
Lamb's-quarters (atrazine resistant)	10	31	54
Pigweed (atrazine resistant)	9	30	53
Cocklebur	6	22	46
Ragweed	5	21	45
Wild mustard	5	18	42
Velvetleaf	4	15	40
Lady's thumb	3	13	36
Wild buckwheat	2	10	31
Eastern black nightshade	2	7	25
Annual grasses			
Volunteer corn			
Giant foxtail	2	10	31
Proso millet	2	10	31
Fall panicum	2	10	31
Barnyard grass	2	7	25
Green foxtail	2	7	25
Yellow foxtail	1	5	18
Old witch grass	1	5	18
Crabgrass	1	3	13
Perennials			
Canada thistle	4	15	40
Milkweed	4	15	40
Perennial sow-thistle	4	15	40
Quackgrass	4	15	40
Horsetail	2	7	25
Nutsedge	2	7	25

Source: Herbicide Application Decision Support System 2001

tivation will be required to control weeds between the bands. Consider the combination of the two operations when evaluating the economics of treating weeds in this manner.

Herbicide Resistance

Herbicide resistance has been found in Ontario. Resistance to triazine herbicides was first found in 1974 and is now present in several species of broadleaf weeds and grasses. In 1997, resistance was found when using ALS (Group 2) herbicides to control pigweeds and in 2000, ALS-resistant Eastern black nightshade and common ragweed were found. Herbicide resistance usually develops from repeated use of the same type of herbicide. Using principles of integrated weed management helps to reduce the onset of resistance and to manage resistance when it is found.

Integrated Weed Management

Weed control in the corn crop is influenced by:

- crop rotation
- seeding rate
- row width
- hybrid characteristics
- tillage practices
- use of custom crop harvesting or planting equipment

In general, the agronomic practices that produce a healthy, fast-growing crop will provide the best competition with weeds.

Crop rotations can be effective in reducing certain perennial weeds that may grow best in a particular crop. Rotating to a different crop can allow different herbicides or tillage practices to be used, which may be particularly effective on specific weed species.

Narrow rows and higher populations tend to increase the crop canopy density and reduce the growth of weeds, but care should be taken to balance the benefits of weed control with the other requirements of the crop.

Fertilizers tend to stimulate the germination of some plant species. Using banded phosphorous and potassium tends to concentrate the nutrients most where the crop has access to them. Side-dress nitrogen applications disturb the soil, which may stimulate the germination of weeds but also places nitrogen in a narrow band and below the depth from which most weeds germinate and grow.

Equipment can carry weed seeds from field to field. Combines, tillage equipment, wind and soil erosion can all transport weeds. Weeds can also infest a field from manure application or other soil amendments. Proper sanitation and cleaning of equipment along with maintenance of field border areas all benefit long-term weed management in the field. Birds may also carry seeds of weeds from field to field.

Please refer to OMAFRA Publication 75, *Guide to Weed Control*, for more information, including herbicide products and rates.

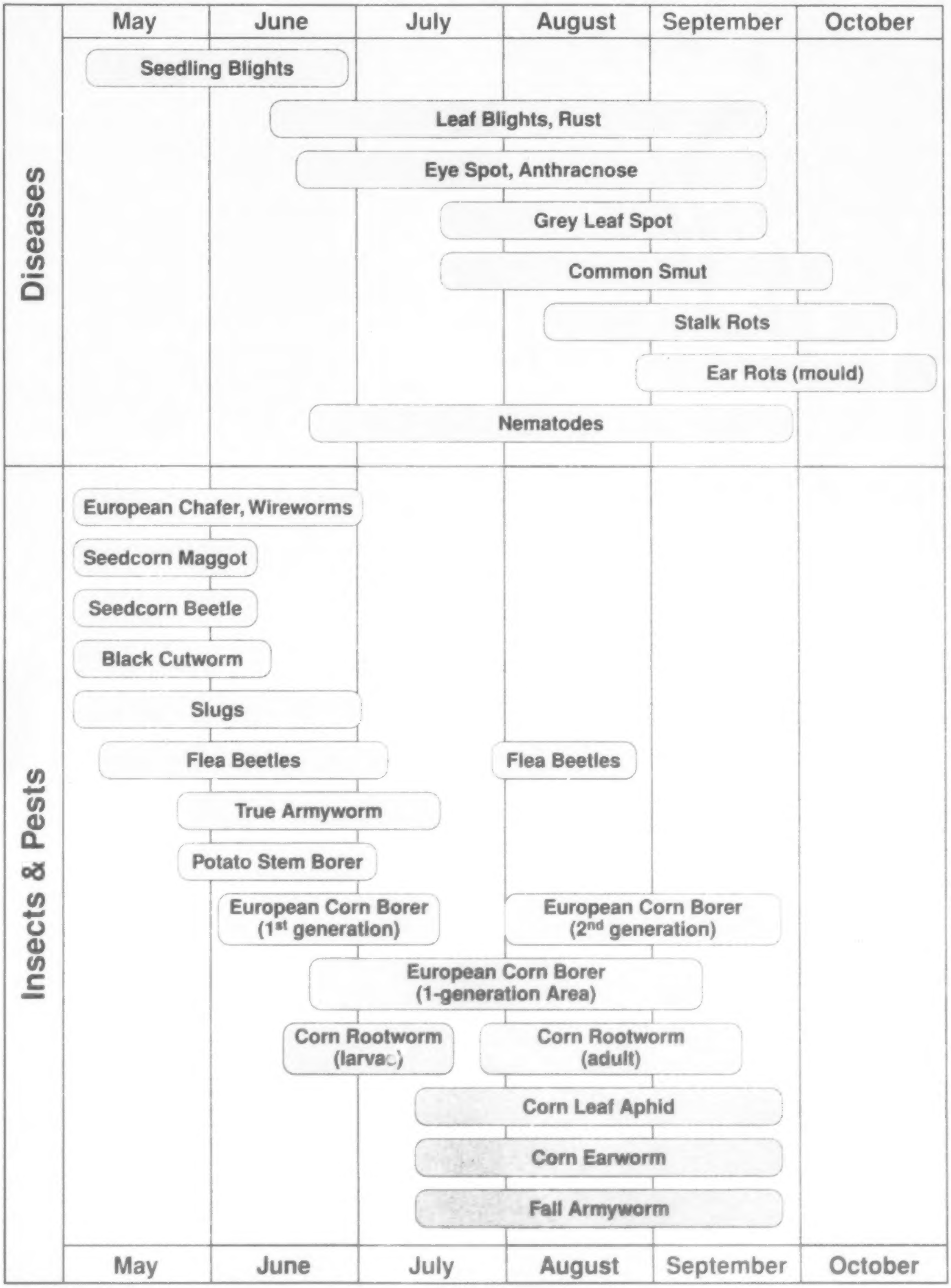


FIGURE 3-2.
Corn Scouting Calendar

Insects

Table 3-27, *Symptoms in the Field,* below, shows insects and pests that could be causing the symptoms in the field.

Individual descriptions of insects found in corn and recommendations for their control follow.

Table 3-27. Symptoms in the Field

	Insects and Pests															
Symptom	Fall armyworm	True armyworm	Black cutworm	Corn earworm	Corn flea beetle	Corn leaf aphid	Corn rootworm adult	Corn rootworm larva	European chafer	European corn borer	Grasshoppers	Potato stem borer	Seedcorn beetle	Seedcorn maggot	Slugs	Wireworms
Gaps in the Stand																
Seed is fed upon or hollowed out													x	x	x	x
Plants are stunted or wilting									x			x				x
Plants are cut off at or below soil level			x									x				
Leaf Tissue Feeding																
Feeding holes are ragged	x	x	x												x	
Pinholes or round, symmetrical holes										x						
Feeding tracks running parallel to leaf veins on upper surface of leaf					x											
Stalk Damage																
Tunnelling within the stalk										x		x				
Stalk "goosenecked"								x								
Ear Damage																
Large chunks or kernels missing:																
• entry hole on side of ear and feeding throughout ear	x															
• no entry hole into ear and feeding concentrated on ear tip				x												
Surface feeding on kernels and/or husk tunnelling										x						
Silks clipped				x							x					
Ears drop										x						
Tassel Damage																
Broken tassels										x						
Tassels discoloured or sticky						x										
Tassels are fed on				x												

Wireworms

Description: Wireworms are larvae that are 7-35 mm long, cylindrical, copper-brown-coloured and hardened (see Plate 9 on page 275). Adult wireworms are beetles that have the ability to flip themselves upright when placed on their backs, making an audible click as they do, giving them their name "click beetles."

Life History: Wireworms take up to 6 years to develop from egg to adult, spending most of their life as larvae. They overwinter as larvae in the soil below the frost line. When soil temperatures warm in the spring, the larvae move to the surface to feed. Due to their long life cycle, the larvae can damage several successive crops, feeding on the roots of weeds, grasses and crop plants. Once soil temperatures become hot and soil moisture decreases, the larvae migrate downward and may be difficult to find later in the season. When it is time to become adults, the larvae migrate back to the surface, pupate, and the adult emerges to mate and lay eggs in grasslands or weedy areas.

Damage: Wireworms are most active during the months of April to June and occur most often in fields that have little disturbance. The larvae attack roots, seeds and germinating seedlings of many crops such as corn, soybeans, wheat, edible beans and potatoes. Non-uniform growth or gaps in the stand may be due to wireworm feeding on germinating seeds. Injured seedlings appear stunted and wilted with leaves sometimes becoming purple or blue at the tips. The problem is usually worse in the second year out of sod after high grass-weed pressure, or when cereals are frequently in the rotation. They are also generally more prevalent in sandier soils, especially on the knolls.

Scouting Technique: Wireworms should be scouted in mid-April, prior to planting. To scout for wireworms, a few weeks before planting, establish two bait stations per high-action site in each field. Dig a hole at each station, approximately 15 cm wide and 5–8 cm deep. Choose one or two high-action sites in the field (i.e., sandy knolls, heavy grass infestations). Bury a nylon mesh bag with 1 cup equal parts untreated and soaked corn and wheat or freshly cut potatoes at the bottom of the station. Mound the soil over the bait to prevent standing water. Return to the stations a few days before planting to sift through the bag contents to record the number of larvae found per station.

Action Threshold: One wireworm per bait station.

Management Strategies: Seed treatments should be used in fields with a high wireworm incidence or following grassy sods. Seed treatments will protect germinating seed but tend not to protect the seedlings. In-furrow or banded insecticides at planting are recommended if populations exceed the action threshold. No rescue treatments are available. For insecticide recommendations, see OMAFRA Publication 812, *Field Crop Protection Guide*. Control grassy weeds in crops previous to corn.

Seedcorn Maggot

Description: The seedcorn maggot is a small, yellowish-white, headless, legless larva (see Plate 53 on page 283). The body tapers to the front with two small mouth hooks protracting. The maggots burrow into germinating seeds and the below-ground parts of emerging seedlings, producing weak seedlings. The adults resemble a small housefly that is slender, light grey and approximately 5 mm in length.

Life History: Seedcorn maggot adults (flies) will mate, and the female will search for an egg-laying site from April until the middle of June. The females are attracted to moist soils that give off an odour of decaying organic matter such as crop residues, areas where manure has been applied or freshly tilled soil. Weeds are also attractive to females. The adults lay their eggs in the soil. The larvae then develop in the soil and organic residue, feeding on germinating seeds.

Damage: Seedcorn maggot is usually a problem during cool, wet springs when germination is delayed. The maggots feed on the swollen, ungerminated seed. They can be found in the cotyledon, embryo and hypocotyl. Slow emergence and or reduced stand establishment can occur. Seedlings that escape and germinate often die or lag behind.

Scouting Technique: Unlike wireworm, seedcorn maggot damage is usually found over a generalized, large portion of the field. Nothing can be done to rescue a damaged field except re-planting if necessary. High-risk factors include freshly tilled soil with heavy crop residue, recently applied manure, recently tilled green manure, deep planting, along with cool, backwards emergence conditions in the forecast. Look for signs of poor stand emergence and feeding damage at the base of the newly emerging plants.

Action Threshold: No threshold is available at this time.

Management Strategies: Consider insecticide seed treatments in early planted fields where large amounts of manure or residue have been recently incorporated. Use good quality seed that will emerge quickly. In-furrow or banded insecticides for rootworm control will also control seedcorn maggot, but it is generally not economic to routinely use granular insecticide for seedcorn maggot control in corn. There are no rescue treatments available. For insecticide recommendations, see OMAFRA Publication 812, *Field Crop Protection Guide*.

Seedcorn Beetle

Description: Seedcorn beetles are small, brown ground beetles, less than 1 cm (¼ in.) long, that are primarily predators of small insects but may feed on the germinating corn seeds under slow emergence.

Beneficial ground beetles look very similar to seedcorn beetles but are usually larger.

Life History: This pest overwinters as adults in the soil. In May, the beetles become active, feed, mate and lay eggs in the soil. There are two generations per year.

Damage: The adult is the damaging stage. Damage is confined to the endosperm of the seed and is usually a problem in cool, wet springs when germination is delayed. Adults hollow out the seeds, preventing germination. Emergence of corn up to the 3-leaf stage is the critical time for damage to occur. Damage is most likely to occur in a situation where weather or soil conditions have delayed seed development. Seedcorn beetles are more commonly found on heavy, moist soil, under reduced tillage with excessive residue cover.

Scouting Technique: Adult beetles are present at the time of seed germination. Dig up unhealthy plants or skips in emergence and examine the seed. Examine 10 seeds or sites in five areas to determine the extent of the problem.

Action Threshold: Replanting may be necessary if skips at proper germination time are extensive.

Management Strategies: See OMAFRA Publication 812, *Field Crop Protection Guide*, for chemical control options.

Planting into warmer soils will reduce chances for seed corn beetles to cause damage.

European Chafer (White Grubs)

Description: European chafer larvae are white and C-shaped with an orange-brown head and dark posterior. This pest can be distinguished from other white grubs by its Y-shaped pattern of anal bristles known as "rasters," located on the underside of the last abdominal segment of the larva (see Plate 10 on page 275). The adult is a medium-sized, light-brown, fawn-coloured, oval scarab beetle, closely resembling the native June beetle.

Life History: This pest overwinters as larvae or "grubs" in the soil below the frost line. In April to mid-May, these larvae migrate back up close to the soil surface and feed on plant roots. Larvae then pupate from mid-May to mid-June, and adult beetles emerge from the soil in early June to early July to mate. Adult chafers congregate in conspicuous mating flights and can be seen swarming at dusk. The beetles fly to tall objects along the horizon, usually trees or other landscape to mate. The adult females then locate cool, moist soil in nearby fields or lawns to lay their eggs in. Eggs hatch and newly hatched larvae begin feeding on roots in late July until the ground freezes. The grubs then migrate down below the frost line to overwinter. There is one generation per year.

Damage: Grubs feed on the fibrous roots, 3–5 cm from the soil surface. Roots are pruned, causing plants to become stunted and wilt. Intense root feeding results in poor emergence and stunted plants. Corn following soybean crops on sandier soils near areas of turf such as lawns, golf courses and pasture is at the highest risk.

Scouting Technique: It is best to scout for chafers in the fall in standing soybean stubble. Scout for chafers on the sandier knolls of the field. Using a shovel, dig up approximately 1 ft of soil, about 3–4 in. deep, for five single soybean plants in each area sampled.

Action Thresholds: No thresholds are available at this time.

Management Strategies: See OMAFRA Publication 812, *Field Crop Protection Guide*, for chemical control options. Avoid planting corn if grub population is extreme, plant soybeans instead. Cultural options include disturbing the soil by tillage or disking, which brings the grubs to the surface where they are exposed to the elements and natural enemies such as birds, skunks, raccoons etc. To be effective, fall plowing must occur before the grubs migrate below the plow depth. Some natural enemies help to control this pest, including parasitic wasps (e.g., pelecinid wasp), parasitic flies, pyrgotid fly and fungus.

Black Cutworm

Description: Larvae are greyish-black with a paler underside and no distinct markings on their bodies (see Plate 11 on page 275). Mature larvae are about 3.5 cm (1 ¼ in.) long and hide in the soil during the day. They can be found near freshly cut plants, under soil clumps or along a poorly closed seed furrow. Adult moths are grey with a small black dagger marking on each forewing.

Life History: Cutworm moths do not overwinter in Ontario but are carried in from the south on strong southerly weather systems. The heaviest immigration occurs from April to May but may occur as early as March. Cutworms are therefore more frequent in fields with green cover early in the spring before primary tillage. There are several generations per year, however, only the first generation causes economic damage in corn. Warm, clear, calm nights in early spring are ideal for moths to lay eggs. Eggs are laid on dense vegetation, low to the ground, and are usually laid before primary tillage in the spring. Feeding occurs from early May through to mid-June.

Damage: Plants attacked by young larvae will have small holes or gouges in the leaves. Plants may suddenly wilt, because the stem has been hollowed out. Larger larvae cut off the plant at or just below ground level. Factors that favour cutworm outbreaks include a history of cutworm damage, presence of winter annual weeds such as chickweed and volunteer wheat before planting, no-till and heavy crop residue.

Scouting Technique: Start scouting for cutworm once every 5 days as soon as your corn emerges. Pay particular attention to those areas where weeds were heavy just before tillage and planting this spring. Look for leaf-feeding (pinholes) by young climbing larvae as the first sign of damage. Also look for wilting plants, foliage-feeding or for plants being cut off at the ground. Dig around damaged plants and search through the soil, as cutworms like to hide in the soil during the day. Note the size of the cutworms found.

Action Thresholds: If more than 10% of plants show leaf feeding, treating at this time will give nearly 100% control. Once corn reaches the 5-leaf stage and begins to produce roots at the base of the plant, the risk has passed. Cutworms that are nearly mature (over 2.5 cm long) are difficult to control and will stop feeding in a few days when they reach full size.

Management Strategies: Insecticide treatment is most effective when applied to the soil soon after cutworms have hatched. Cutworms are most active in the evening, therefore insecticides applied at this time of day are most effective. It is not necessary to treat the entire field, only those areas showing evidence of feeding. Refer to OMAFRA Publication 812, *Field Crop Protection Guide*, for recommended control products. Only a small acreage of Ontario corn has cutworm problems in any given year, therefore using granular insecticide at planting time is not recommended. Insecticide application to mature larvae is not recommended since most of the damage is done. In no-till corn fields, it is important to have no green vegetation that could attract the moths in early spring. Fall burndown of volunteer crops and other weeds is recommended. Fields should be bare for at least 2 weeks before planting.

Slugs

Description: Juveniles and adults are soft-bodied, legless, greyish or mottled in appearance and have a slimy or gelatinous covering that helps keep them from drying out. The head has two pairs of tentacles. Slugs usually range from 1–3 cm in length but can reach up to 10 cm.

Life History: There is one generation per year but two populations, one maturing in spring and one maturing in fall. Therefore, both eggs and adults are found overwintering. Juvenile slugs hatch from eggs in the spring and the fall. They are active during cool and wet periods of the year. Slugs prefer environments with high humidity and relatively cool temperatures. Debris, such as crop litter or manure, provides them with shelter from the sun.

Damage: Slugs feed above or below ground depending on the moisture level. They can feed on germinating seeds and seedlings with no real preference for a plant part (see Plate 12 on page 275). On larger plants, slugs feed on lower parts, eating partly or completely through leaves, leaving ragged holes causing a skeletonized appearance on leaves (see Plate 55 on page 283). Feeding damage can resemble that caused by hail, and severe defoliation can result. If slug populations are high, they may feed on germinating seeds before they emerge. Higher-risk fields include those where no-till practices on corn are used for a continuous period of time, fields with considerable crop residue and fields following forages, especially grasses.

Scouting Technique: Scout for slugs at night or in the early morning hours, when they are active (nocturnal). Look for stripping of leaf tissue and/or small holes chewed in the leaves. Check under debris and clumps of soil. A certain sign of slugs is a slimy, silver-coloured trail on the plants or soil. Check 1.5 m of row in five locations in the field (under clods and pieces of plant residue).

Action Threshold: No action thresholds are available. Most corn seedlings grow out of slug damage because the growing point is usually protected from damage in the whorl. Once plants have more than 8–10 leaves, the risk of damage is greatly reduced.

Management Strategies: Tillage can be used against slugs since the elimination of the crop cover exposes the slugs to dehydration and predation by birds and mammals. Zone tillage or row sweepers can help speed up the drying of the row area, thus deterring slug feeding. Moving trash away from seedlings may help reduce damage. There are presently no economical and effective chemical methods available for slug control. Refer to OMAFRA Publication 812, *Field Crop Protection Guide*, for any future chemical control options.

Corn Rootworm

Description: There are two species of corn rootworm in Ontario. Western corn rootworm (WCR) adults are yellow to green with three, wavy black stripes on their wings (see Plate 13 on page 276). Northern corn rootworm (NCR) adults are uniformly green to yellowish (see Plate 14 on page 276). Larvae are white with a brown head and a distinct dark tail plate; they are approximately 1 cm in length.

> Do not confuse the western corn rootworm with the striped cucumber beetle. The striped cucumber beetle's abdomen on the underside is black, and its stripe is distinctly paralleled, not wavy.

Life History: Both WCR and NCR are uniformly distributed across Ontario at a ratio of about 85% western to 15% northern. Both have only one generation per year. Eggs are deposited in the soil from July until a killing frost in the fall. The eggs overwinter and hatching begins in early June. Adults emerge in late July where they feed on silks and tassels. If tassels have not emerged they will feed on the leaves, stripping tissue on the underside of leaves between the veins leaving "window panes."

Damage: Larvae feed on and within the roots from mid-June to mid-July, interfering with nutrient and water uptake, causing stress to the plant. Larger larvae feed on the brace roots, reducing the stability of the plant, causing it to lodge or gooseneck. Adults feed on pollen and clip the silks, interfering with pollination. Risk factors include heavier soil (clay), high beetle populations in corn of previous season and being the latest field planted in the previous season.

Scouting Technique: Monitor 20 plants in five different locations in your field weekly from when adults emerge at the end of July to the end of August.

Action Thresholds: If there is less than one beetle per corn plant on average throughout the month of August, then no insecticide is necessary in the following corn crop. (Note: 1 WCR = 2 NCR when counting adults). Field corn can withstand heavy adult populations (more than 10 adults per ear) at pollination without economic loss. After pollination is complete, beetle feeding no longer poses a threat to yield. For seed corn, foliar insecticides for control of adults may be necessary if adult populations are high enough to cause extensive silk clipping and pollination disruption.

Management Strategies: Crop rotation is the best strategy for control. Since corn is the primary host crop, avoid planting corn on corn. Continuous corn fields produce up to 4 million beetles per hectare. Although rootworm insecticides can protect the crop from damage, on average they reduce beetle emergence by only 25%. Crop rotation is thus far superior to insecticides for reducing rootworm populations. If crop rotation is not practical, it may be necessary to treat second-year corn, especially on clay soils. If extensive goose-necking occurs or monitoring for adults in August shows significant populations, consider insecticide treatments the following spring if corn is to be replanted in that field. For soil-applied insecticide recommendations, see OMAFRA Publication 812, *Field Crop Protection Guide*.

European Corn Borer

Description: Egg masses are flat, creamy white and layered over each other, making the egg mass appear similar to fish scales (see Plate 15 on page 276). Mature larvae are creamy white to pale grey with 2 small spots per abdominal segment, approximately 2.5 cm in length and have a black head (see Plate 16 on page 276). Adults are light-brown moths approximately 2 cm long with dark wavy lines running across each forewing (see Plate 17 on page 276). Male moths are darker and smaller than females.

Life History: There are two distinct strains in Ontario. South of a line from Sarnia to Simcoe, there is a bivoltine strain that can undergo multiple generations depending on the length of the season. North of this line, there is a univoltine strain that has only one generation per year, however, locations in southern Quebec also have two generations per year. There is a band of overlap for these two strains, about 50–80 km wide along this line.

Overwintering: The insect overwinters as larvae in corn stalks and other residue left on the surface from the previous growing season. As day length increases and average day temperatures exceed 10°C, the larvae pupate. Pupae are found within larval feeding tunnels and require 2 weeks to develop before adults emerge.

Emergence: While emergence begins around the third week of May in the southernmost regions of the province, moths do not usually appear until mid-June in eastern Ontario. Once moths emerge, they fly to nearby "action sites" or vegetative habitats such as fencerows, ditches and hedgerows along fields.

Development: Once mated, females leave the action sites to lay eggs on the host crop. Eggs are generally laid on the underside of leaves, close to the midrib. Where univoltine ECB are present, larvae develop through the season until autumn, when as fifth instars they prepare for overwintering. Where bivoltine ECB are present, first-generation larvae will pupate in mid-summer, emerge as adults and complete a second generation before entering diapause in the fall.

Damage: Early-season larvae feed on leaves, creating small pinholes and eventually migrate into the whorl of the plant and attack the enclosed tassel. Later-season larvae feed briefly on the leaves, bore into the midrib of the leaf and then migrate into the stalk of the plant and husk of the ear. Larvae may also feed directly on the developing kernels. Stalk lodging and ear droppage may occur as a result of significant infestations. This pest can carry both stalk rots and ear rots into the plant. High-risk factors include no-till fields with high residue, those with frequent corn crops in cycle, regions with a high percentage of corn (50% or greater in region) and regions where univoltine and bivoltine strains overlap.

Scouting Technique: Early-season moths are attracted to taller, early-planted corn fields while later-planted fields are more susceptible to second generation corn borer where female moths are attracted to silking and tasselling fields. Examine a minimum of five sets of 20 plants per field (100 plants per field).

Economic Thresholds: Refer to Appendix E, *European Corn Borer Economic Threshold Calculations,* on page 261, to calculate ECB economic thresholds.

For first generation scouting, look for leaf-feeding damage. Pull out and unroll the whorl of the damaged plants, looking for small larvae. Split the stalk of the plants from top to ground to locate older larvae. Record the percentage of damaged plants and number and size of larvae found.

For second generation scouting, look for egg masses on the underside of the leaves, close to the midrib of the plant. Concentrate scouting efforts to the three leaves above and below the ear of the plant. Record the percentage of plants with egg masses. Repeat scouting every 5 to 7 days until peak moth flights have subsided in your region (approximately 1 month).

Management Strategies: If ECB is a moderate to high risk in your region, consider planting transgenic Bt corn hybrids. Use corn hybrids that express the Bt toxin in the ear as well as the stalk to help avoid stalk and ear rot.

If using Bt corn, it is imperative that a refuge of at least 20% of non-Bt corn is planted along with the Bt corn to reduce the chance of developing resistance to Bt. This refuge can be achieved by planting strips of at least six rows wide (e.g., three planter boxes on an 8–12 row planter) or by planting blocks of non-Bt corn. In all cases, all Bt corn plants should be within 400 m of non-Bt corn. Do not mix Bt and non-Bt seed to achieve refuge.

Insecticides have generally not provided economic control of ECB in field corn. Using Bt transgenic corn provides much better control. Shredding debris after harvest is an effective way to destroy borers overwintering in stalks and stubble; leave as little stalk as possible. Select hybrid varieties of corn with resistance or tolerance to ECB feeding and adapted to your area. Immature stages of ECB are attacked by natural enemies, which contribute to reducing population densities. Predators such as ladybird beetles and minute pirate bugs feed on the eggs and young larvae. Parasitic wasps and predaceous mites can also help to control this pest.

For further information on ECB or Bt corn, refer to OMAFRA Publication 12, *Sweet Corn Production Manual,* and the Canadian Corn Pest Coalition publication, *A Grower's Handbook; Controlling European Corn Borer With Bt Corn Technology,* available at www.ontariocorn.org/btguide.html.

True Armyworm

Description: True armyworms, full grown, are 4-cm (1 ½-in.) dull-green to brown larvae that can be easily confused with other caterpillars, including variegated cutworm and fall armyworm. Two distinguishing features that true armyworm possess are white-bordered stripes running laterally along the body and dark diagonal bands at the top of each abdominal proleg (see Plate 18 on page 277). The head is yellow-brown with a network of dark brown lines creating a pattern. The adult sand-coloured moth has distinctive white spots on the centre of each forewing.

Life History: In early spring, the moths prefer to lay their eggs in grassy vegetation. Larvae hatch from the eggs and feed at night or on overcast days for approximately a month. There are two generations per year, but it is the first generation that tends to do the most damage in corn in Ontario.

Damage: True armyworms feed at night. In conventional-till cornfields, damage usually occurs first in the border rows, whereas infestations may develop throughout no-till corn following small grains or grass. True armyworm also frequently invades corn fields from neighbouring cereal fields. Feeding begins on the margins of leaves and eventually the plant is stripped of leaves, with only the stalk and leaf midribs left. As long as the growing point of the plant is not damaged, the corn plant will be able to recover from moderate feeding.

Scouting Technique: The best time to scout for true armyworm is early evening, just before sunset. Examine 20 plants from five locations in the field (100 plants total). During the day, you may find the larvae in the whorl, leaf axil, amongst the crop debris on the soil surface or under soil clods. Also, you may find brown frass, often mistaken for eggs, in the whorl or on the soil near the plant. Record the size and number of larvae.

Action Threshold: As long as the growing point of the plant is not damaged, the corn plant is usually able to recover from moderate feeding. With early season feeding, insecticide may be warranted in seedling corn if there are two or more larvae per seedling and feeding damage exceeds 10%. For corn past the whorl stage, if 50% of the plants are showing damage and are infested with larvae smaller than 2.5 cm (1 in.), then insecticide treatment may be warranted. When scouting, check the backs of armyworms for eggs. These small, oval, yellowish eggs are usually located just behind the head of the larva. These are eggs of a parasitic fly. The eggs will hatch, and the maggots will kill the armyworm larvae.

Management Strategies: If the larvae are almost full grown (about 4 cm (1½ in.) long), there is no benefit in applying insecticide since most of the feeding damage has already been done. Insecticides will only be effective on larvae that are smaller than 4 cm (1½ in.). Refer to OMAFRA Publication 812, *Field Crop Protection Guide,* for insecticide recommendations. Treatment may be confined to infested areas. The parasites and other beneficial organisms usually keep armyworms from reaching damaging levels. Avoid treating with insecticides when large numbers of parasitized larvae are present. Because grassy, weed-infested corn is attractive to armyworm moths for egg-laying, eliminate weeds from the corn crop and field borders. Late-season grass control may not be a good option since this will cause the feeding larva to migrate from the grassy weeds that are now dead to the crop itself.

Fall Armyworm

Description: Full-grown fall armyworms are 4 cm (1½ in.) long, varying in colour from light tan or green to near-black (see Plate 19 on page 277). Three white, thin strips run down the back with one thicker, yellow band with red spots running along the side, just above the legs of the larvae. Scattered along the body are black spots called tubercles that have spines coming from them.

The fall armyworm larvae can be distinguished from the true armyworm by a white, inverted "Y" on the front of the head of the fall armyworm. The fall armyworm head is dark brown to black.

The adults are dark grey moths with a mottled pattern on their wings. A white spot can be found on the tip of the wing.

Life History: Fall armyworm adult moths migrate from the southern states and show up later in the season when the corn is fully grown. This insect cannot overwinter in areas where the ground freezes.

Damage to the ear is similar to that of corn earworm, however, the fall armyworm entry hole can easily be seen coming from the side of the ear, and feeding is throughout the ear. Corn earworm enter the ear through the silk channels, and feeding is typically concentrated close to the tip of the ear.

Damage: Fall armyworm is an occasional pest of grass crops such as corn and wheat. The larvae feed on the whorl leaves and ears predominately from late July to September. Fall armyworm feeding occurs in the daytime, unlike true armyworm feeding, which occurs at night. Initial leaf feeding appears as ragged-edged holes; moist, reddish brown frass can be found nearby.

Scouting Technique: Examine 20 plants from five locations in your field to determine the level of infestation. Record the size and number of larvae. When scouting, check the backs of armyworms for parasite eggs. These small, oval, yellowish eggs are usually located just behind the head of the larva. These are eggs of a parasitic fly whose maggots will kill the armyworm larvae.

Action Threshold: If 50% of the plants are infested with larvae smaller than 2.5 cm (1 in.), insecticide treatment may be warranted, but damage is usually not economical unless infestations are high and feeding is concentrated on the undeveloped tassels.

Management Strategies: For insecticide recommendations, see OMAFRA Publication 812, *Field Crop Protection Guide*. Armyworm tend to move in large numbers from one field to another. When this happens, it is advisable to spray the border of the invaded field. **Chemical control is not effective on larvae larger than 2.5 cm (1 in.) or on those concentrated in the ear.** Parasites and other beneficial organisms usually keep armyworms from reaching damaging levels. Avoid treating with insecticides when large numbers of parasitized larvae are present. Late-planted corn is most susceptible to leaf and whorl feeding. Grassy areas in and along the field borders are attractive to the egg-laying moths, therefore, eliminating grasses and weeds from the corn field is recommended. Late-season grass control may not be a good option since this will cause the feeding larva to migrate from the grassy weeds that are now dead to the crop itself.

Corn Earworm

Description: Corn earworm larvae vary greatly in colour from light green to yellow. The full-grown larvae are 4 cm (1½ in.) long with prominent stripes running the length of their bodies (see Plate 20 on page 277).

> The size and the presence of the stripes differentiate earworms from European corn borer, while their tan head colour differentiates them from fall armyworm.

Adult moths are buff or tan coloured. The forewing has a central brown dot visible from the underside of the wing, and the hind wings are pale in colour with a darker brown border.

Life History: Corn earworm, also known as cotton bollworm — a pest on cotton, does not overwinter in Ontario but migrates as adult moths from the southern states. Usually they arrive in Ontario in August but they may come as early as late June. The moths will then lay their eggs individually on fresh silks. The eggs hatch, and the larva feed on the silks and kernels at the ear tip. Larva will pupate but die soon after frost.

Damage: Larvae may feed on leaves and tassels but mainly are found feeding on silks and developing kernels. Larvae damage tassels, causing poor pollination, and consume silks, affecting ear development. Fields at risk are those planted late that will be freshly silking during peak population time.

> Unlike European corn borer and fall armyworms, corn earworm does not leave entry holes into the ear husk but instead concentrates its feeding at the top third of the ear tip, leaving a messy ear tip.

Scouting Technique: Locate five sets of 10 plants per field and open the ear and inspect for feeding damage or larval presence, including the presence of ear moulds carried in by the pest. Determine the percentage of ears infested. Corn earworm is cannibalistic and, therefore, there is usually no more than one larva per ear of corn.

Action Thresholds: This pest is usually only an economic pest in sweet corn but can affect late-planted seed corn fields that are silking at time of egg laying.

Management Strategies: Earlier-planted corn may have a chance to escape the peak infestations of corn earworm if they silk early enough. Insecticides have generally not provided economic control of corn earworm in field corn. There may be some value in treating seed corn to maintain kernel quality. Several natural enemies exist in the field, including trichogramma wasps, ladybird beetles, lacewings and parasitic flies, which help to keep pest populations in check.

Corn Flea Beetles

Description: Very tiny (1.8mm), black, shiny beetles with elongated hind legs used for jumping when disturbed (see Plate 21 on page 277).

Life History: This pest overwinters as adults at the base of grasses. In the early spring, beetles emerge and mated females then lay their eggs in the soil close to the base of corn plants. Within 6 days, eggs hatch into larvae, which then pupate, and within 14 days, the adult beetle emerges from the soil. There are three to four overlapping generations per year. Only those generations occurring from early May to late June, during corn emergence are considered a potential problem.

Damage: Only susceptible varieties show yield loss. Long feeding scratches or window-paning are found on the leaves, usually running parallel with the leaf veins. Flea beetles vector Stewart's bacterial wilt (*Erwinia stewartii*), which shows up on the plant as linear lesions with wavy edges. Plants may wilt or become stunted from this disease.

Scouting Technique: Inspect five sets of 20 seedling plants per field to determine the presence and density of the beetle.

Action Thresholds: An average of five or more beetles per plant prior to the fourth-leaf stage may warrant control.

Management Strategies: Mild winters favour the survival of the beetle and bacteria over the winter. Early planting dates should be avoided for varieties susceptible to Stewart's wilt. It is uneconomical to spray corn with insecticides to protect against Stewart's wilt except in seed corn with highly susceptible varieties. Seed treatments are being developed for flea beetle control. See OMAFRA Publication 812, *Field Crop Protection Guide*, for chemical control options.

Potato Stem Borer

Description: Larvae are light purple to pink, approximately 4 cm (1½ in.) in length when mature (see Plate 22 on page 277). Adults are brown moths that are active during August and September.

Life History: This pest of corn is more severe in the eastern counties, but infestations occur throughout the province. There is one generation per year. This pest overwinters as eggs in grasses. Eggs are laid in two or three parallel rows under the leaf sheath. These hatch in late April, and the small larvae initially bore into the stalks of grass plants. By late May, the larvae outgrow the grass stalks and move to nearby thicker stalk crops such as corn. These larvae continue to feed until late June, pupate and emerge as adults in late July.

Damage: Larvae are the only damaging stage. Damage is usually most severe at field edges or near grassy, weedy areas. Larvae feed on plants in late May or early June. On young plants, the larva will burrow into the base of the plant, below the soil line. Plants may be cut at the base, similar to cutworm injury. At the three- or more leaf stage, they feed inside the whorl at the base of the corn plant, causing the upper one or two leaves to wilt, while the lower part of the plant remains healthy. Fields at higher risks include grassy or weed-infested fields of previous year, fields following sod and conservation-till fields.

Scouting Technique: Usually found within the stem or in soil near the base of the plant. Look for potato stem borers along fencerows or in grassy areas

Action Threshold: No action thresholds are available at this time.

Management Strategies: There is no effective or economic chemical control for these insects since the borer remains inside the plant and is protected. Good weed control this year (especially of grassy weeds) will reduce the risk of damage next year. Fall plowing or burndown can reduce the number of eggs to overwinter. There are parasitic wasps that generally keep this pest below economically damaging levels.

Corn Leaf Aphids

Description: These aphids are small (2mm or less), bluish green, soft-bodied insects with black legs and short black cornicles ("tailpipes") near the rear of the abdomen (see Plate 23 on page 278). They have piercing and sucking mouthparts and feed on the juices (nutrients) of young plant tissue (tassel and whorl). They secrete a sticky substance referred to as "honeydew," which can become coated with a blotchy, sooty mould.

Life History: This pest does not overwinter in Ontario but instead is carried each year by air currents from the south where crops are more advanced. Initial spring migrants feed on winter barley, until corn becomes attractive. Migrating populations are comprised of winged females only. Once they settle, these females reproduce without mating and give birth to live wingless nymphs. Both winged and wingless adults are produced, depending on the nutrient quality of the plant. Winged aphids then fly to nearby corn fields and enter the whorl. There are several generations per year.

Damage: The degree of feeding injury depends on the size of the population. Nymphs and adults feed primarily on the whorls of the plant, removing nutrients and water. Symptoms include yellowing, wilting and curling of the leaves. During drought conditions, symptoms may be amplified. As densities increase, leaf surfaces and tassels often become black and sooty as mould begins to grow on the honeydew. Tassels may become gummy, causing poor pollination. They also may vector maize dwarf mosaic virus and barley yellow dwarf virus.

Scouting Technique: Examine five sets of 20 plants per field.

Action Thresholds: If 50% of all plants during late-whorl to early tassel have 400 aphids per plant, and plants are under drought stress, control is required.

Management Strategies: Chemical control is warranted only if the natural enemies and parasites of the corn leaf aphids are not present and aphid densities are above their economic thresholds. There are several biological control agents that exist and are quite effective. These include ladybird beetle adults and larvae, lacewing adults and larvae, and a few parasitic wasps.

Sap Beetles

Description: Adult sap beetles, also known as picnic beetles, are 4 mm (approximately $^{1}/_{6}$ in.) in length, dark brown to black with two pale yellow spots on each wing cover (see Plate 24 on page 278).

Life History: This pest overwinters as pupa and adults in plant debris, most often in rotting corn ears. Adults may become active by mid-April in Ontario. Females deposit eggs in May and June near or on rotting vegetation. Larvae can be found in mid-May and pupate in soil within tightly compacted earthen cells. Adults emerge in 7–9 days.

Damage: Sap beetles do not cause the primary damage on corn. Instead, they feed on bruised, damaged tissue caused by armyworms, European corn borer and birds that feed on the ear tips. Adults feed on exposed ear tips usually during the blister or milk stage. Adults may carry *Fusarium* into the ear from rotting corn residue.

Scouting Technique: Sap beetles are attracted to fermenting sugars and often arrive in large numbers at sweet corn ears that have been previously damaged by birds or other insects. Scout five sets of 20 plants throughout each field.

Action Thresholds: In seed corn fields, control may be necessary if populations are higher than 10 adults on ear tips of 25% of plants scouted. Control is rarely justified in commercial field corn.

Management Strategies: Control insects, birds and diseases in the field that damage or cause injury to the crop. Remove or deeply bury all decaying plant material. Damage is less where varieties with long tight husks are grown and where corn earworm is controlled by pesticides. Natural control usually occurs due to a fungal parasite *Beauveria bassiana*. Insecticides are usually not economical.

Diseases

Seedling Diseases

Seed Rot, Seedling Blight and Root Rot

Incidence: Cool or wet conditions that reduce or delay corn germination or seedling development can also lead to early-season seed rots, seedling blights and/or root rots. Poor stand establishment, non-uniform emergence, "gaps" or missing plants are primary symptoms of seed or seedling infection. There are several different fungi that can cause these diseases. The most common are *Pythium, Fusarium, Gibberella, Trichoderma* and *Penicillium,* but other fungi such as *Diplodia* and *Rhizoctonia* could be involved. All of these organisms are found in Ontario soils. Depending on the year and field conditions, their impact ranges from minor to severe (replant). Low-lying or poorly drained areas of the field are often the first to show disease problems. Seed rots and seedling blights are more severe in no-till or reduced tillage fields since heavy residue will keep soil temperatures cooler and wetter longer than conventional fields. Damping-off will occur in conventional fields when the crop is planted early into conditions that favour disease development or when environmental conditions cause the corn seed to sit in the ground for a prolonged period of time. Other factors that delay germination and emergence such as compaction, crusting, deep planting, etc., can also result in a poor stand. Plant vigour is often reduced in those plants that do survive. It is important to distinguish between seedling diseases and other potential problems such as insects, herbicide injury, soil compaction, etc.

Appearance: Seed rots are diseases that affect seeds prior to or shortly after germination. In this case, the seed or the developing embryo has rotted and died. Seeds that have been damaged or have poor seedling vigour are the most susceptible to seed rots, particularly when soil conditions are cool (10°C–13°C or 50°F–55°F) and wet for an extended period of time after planting. Seedlings that take a long time to emerge are most susceptible to fungal infection.

Seedling blights or "damping-off" are characterized into two groups, preemergence and postemergence seedling blights. Preemergence seedling blights affect young seedlings prior to emergence. Affected seedlings may die or grow slower than healthy unaffected seedlings. Postemergence seedling blights (damping-off) affect the roots or lower stems of young seedlings from emergence to second- or third-leaf stage.

Root rot–causing organisms infect the seedlings' root system, including lateral roots and root hairs. Affected plants may be stunted, off-colour or lack vigour. Infection can result in seedling death when disease infection is severe, and infected plants may be more susceptible to stalk rots later in the season.

Seed, seedling and roots infected by *Pythium* are most often soft (wet) and dark coloured as opposed to roots infected with *Fusarium, Gibberella, Diplodia* and *Rhizoctonia,* which are firm or leathery. The colour of the roots most often provides a good indication of which organism(s) are present: Greyish-white indicates *Diplodia,* tan to pink indicates *Fusarium* or *Gibberella,* reddish to brown indicates *Rhizoctonia* and blue-green indicates *Penicillium* or *Trichoderma.*

Disease Cycle: *Pythium, Fusarium, Gibberella, Diplodia, Rhizoctonia, Penicillium* and *Trichoderma* all live and thrive in the soil. In most cases, they can affect other crops beside corn. Except for *Pythium,* all of these organisms also have the ability to live on or in corn seed.

Management Strategies: Planting corn seed with good germination and seed vigour will substantially reduce your risk of seed rots and seedling blights. Seeds that are cracked or have been damaged through harvest or handling are most prone to these organisms and should be removed. Seed treatments will provide additional protection to young vulnerable seedlings. It is recommended that all seed corn be treated with a fungicide seed treatment to prevent early season preemergence and postemergence disease problems. For more information on seed treatments, see OMAFRA Publication 812, *Field Crop Protection Guide.* Other management tactics that minimize soil compaction and remove excess moisture through increased drainage can also help reduce the severity of disease infections.

Corn Leaf Diseases

Anthracnose

Incidence: Anthracnose has been found in Ontario and may become severe in warm, wet years. It is often the first corn leaf disease that is noticed. It begins on the lower leaves, working its way up the plant. Symptoms often disappear as the corn plant begins its rapid growth phase. The fungus that causes anthracnose leaf blight is also responsible for anthracnose stalk rot. Producers should record where anthracnose leaf blight symptoms developed early in the season and return to those areas to scout for stalk rots a few weeks before harvest. Tillage systems that leave considerable amounts of anthracnose-infected debris on the soil surface may lead to greater severity of the disease and an increased presence in Ontario.

Appearance: Anthracnose may affect both leaves and stalks. The main symptoms are leaf spotting, top dieback and stalk rot. Leaf spots are oval (up to 15 mm (6 in.) long) with a tan centre and reddish-brown border (see Plate 25 on page 278). Individual lesions may join, forming streaking along the margin or midrib. A general yellowing of the tissue surrounding the infected areas often develops. With the aid of a hand lens, small black spots (ascervuli) can be seen in the centre of the lesions. Under close examination, black hairs (setae) may be seen protruding from these spots. The disease is first observed on the lower leaves and later on the upper leaves. Top dieback can occur late in the season as diseased leaves wilt and gradually die, taking on the appearance of frost damage.

Disease Cycle: Residue is an important component in anthracnose development, since the fungus survives (overwinters) as mycelium or sclerotia within corn residue or seed. Rain splashes spores from the corn residues onto the lower leaves and stalk. For this reason, corn fields that follow corn (second-year corn) are the most prone to anthracnose infection, especially when the weather is warm and wet.

Management Strategies: Planting anthracnose leaf blight–resistant hybrids can help to manage anthracnose leaf blight. However, resistance to anthracnose stalk rot is separate from resistance to anthracnose leaf blight. Hybrid resistance to anthracnose stalk rot does not guarantee resistance to early-season anthracnose infections on leaves. In conventional corn fields, removal of corn residues through tillage will lower your risk to the disease especially when corn follows corn. In no-till or reduced tillage fields, management of anthracnose leaf blight is best achieved with rotations (avoiding second-year corn) and planting of resistant corn hybrids. Fungicide applications are not economical in field corn situations because more than one application is necessary to control the disease. However, in seed corn fields, fungicide applications may be cost effective.

Northern Leaf Blight

Incidence: Northern leaf blight has traditionally been one of the most damaging corn leaf diseases in Ontario. Use of resistant hybrids has limited yield losses from this disease in commercial corn, however, significant losses continue to occur in seed corn production when highly susceptible corn inbreds are planted.

Appearance: The disease appears as long, elliptical (2–15 cm (1–6 in.)) greyish-green or tan streaks. Lesions most often begin on the lower leaves (see Plate 26 on page 278). As the disease develops, individual lesions may join, forming large blighted areas. In some cases the entire leaves may become blighted or "burned." Losses due to northern leaf blight are most severe when the leaves above the ear are infected at or slightly after pollination. The disease is often confused with Stewart's wilt (see the section *Bacterial Leaf Blight or Wilt (Stewart's Wilt)*, below).

Disease Cycle: The fungus survives in corn residue as either spores or fungal strands (mycelium). The spores of the fungus are spread from the ground residue to the developing corn plant through wind or rain "splashing." Although the fungus does overwinter in Ontario, a major source of spores remains the U.S. Midwest corn belt and surrounding Great Lakes states. Plants that become infected act as a secondary source of infection and may spread to other fields. Disease development is favoured by moderate temperatures (18°C–27°C or 64°F–81°F) with prolonged periods of humid or rainy weather.

Management Strategies: Northern leaf blight exists as four races, and most of the commercial corn hybrids have resistance or tolerance to the most common races that occur in Ontario. An increase in northern leaf blight symptoms in an area could indicate the potential for a new race developing and should be reported. Crop rotation and tillage will reduce inoculum levels in surface residues. In reduced tillage systems, rotation and resistance are necessary. Chemical control is not usually economical in field corn.

Eyespot

Incidence: Although eyespot normally causes minor losses in corn, the disease has been increasing in Ontario with the shift to leaving corn residue in the field.

Appearance: The disease produces characteristic round or oval spots (1–4 mm ($^1/_{16}$–$^1/_8$ in.)) with a tan/brown centre and a brown or purple margin (see Plate 27 on page 278). A translucent yellow halo forms around the margin, and when held to the sun, the lesions resemble an eye. Leaf blighting may occur when these lesions join, killing large portions of leaf tissue. The disease may be confused with non-infectious physiological leaf spots or insect damage.

Disease Cycle: The disease is more prevalent under continuous corn and reduced tillage systems, since the fungus overwinters in corn residue. Disease development is favoured by cool, wet conditions.

Management Strategies: Resistant varieties, crop rotation and clean plowing of crop debris help to reduce disease severity.

Bacterial Leaf Blight or Wilt (Stewart's Wilt)

Incidence: Although bacterial leaf blight occurs throughout Ontario, the disease is a major concern in Southwestern Ontario. Essex and Kent counties, where the majority of seed corn production fields are located, tend to be especially affected by bacterial leaf blight. Warmer-than-normal winters in this area have allowed the corn flea beetle, which vectors bacterial leaf blight (Stewart's wilt), to survive in higher numbers.

Appearance: There are two distinct phases of the disease that occur in Ontario, the late phase and the wilt phase. The wilt phase affects primarily highly susceptible seed corn inbreds and sweet corn hybrids early in the year (V2 to V4). The first noticeable sign of the disease appears as long, yellow streaks that extend along the length of the leaf (see Plate 28 on page 278). These streaks will take on a water-soaked appearance and eventually become brown, dead streaks (necrotic). The bacteria interrupt the water and nutrient movement in the plant by plugging the vascular system of the plant. The result is a rapid wilting and even death. Since the new growth is affected, the wilting and death occur from the top down. Cutting the plant lengthwise will reveal a discoloured, rotted or hollowed-out growing point.

The leaf blight phase or late-infection stage often occurs after tasselling and is the most common. Symptoms include pale green to yellow streaks with irregular or wavy margins that run parallel to the veins. These streaks may run the full length of the leaf. Infected leaves eventually become dry and brown. Often corn flea beetle–feeding marks are visible within the lesions. Premature leaf death can result in reduced yield and an increase in stalk rots since weakened plants are more susceptible to stalk rots.

Disease Cycle: The bacteria overwinters in the gut of adult flea beetles, which hide through the winter in protected areas. Mild winters can result in higher beetle numbers. Overwintering adult flea beetles feed on corn in the seedling-to-whorl stage, and susceptible varieties will develop a stem wilt resulting in complete plant loss. This occurs rarely in hybrids but occasionally in susceptible seed corn parents. The next generation of adult beetles emerges after corn silking and causes leaf wilting symptoms, which are commonly seen in many hybrids. Seed transmission is rare. Most often, late infections after silking are associated with high beetle populations. Sweet corn is often more susceptible than field corn and can serve as a reservoir for the bacteria. The disease is often found in the best fields, and fertility seems to play a part. Susceptibility to the disease increases in fields that have high nitrogen and phosphorous levels.

Management Strategies: Field corn has good tolerance to Stewart's wilt and therefore no control is required, but certain seed corn inbreds are susceptible and are rated for disease tolerance. This disease is controlled by managing the corn flea beetle. For further management information, see the section *Corn Flea Beetles*, on page 83.

Grey Leaf Spot

Incidence: Grey leaf spot has been increasing in the surrounding Great Lakes states and has recently been developing in Southwestern Ontario. Significant losses can occur from this disease under warm, wet and humid conditions.

Appearance: Symptoms develop on the lower leaves soon after tasselling. The disease has unique, elongated (2–7 cm (1–3 in.) long), narrow, light-tan, rectangular lesions. These lesions run parallel to the leaf veins. As the lesions mature, they become grey and join, killing or blighting entire leaves.

Disease Cycle: Grey leaf spot is most problematic when corn follows corn in fields with a considerable amount of corn residue. The fungus survives as fungal strands (mycelium) in corn residue. Spores produced on the residue are dispersed by wind and rain splash. Warm, humid weather helps spore and disease development.

Management Strategies: Some hybrids are tolerant to the disease, and crop rotation and tillage will reduce inoculum levels in surface residues. In reduced tillage systems, rotation and hybrid resistance are necessary. Chemical control is not usually economical in field corn.

Common Rust

Incidence: Common rust does not overwinter in Ontario but instead originates from infected corn in the southern United States and Mexico. Rust spores are blown into Ontario from these infected corn plants. In most years, rust is of minor economic importance, however sometimes spring storm fronts bring in spores and cause early season infection. The disease is favoured by high humidity with cool evening temperatures (14°C–18°C) followed by moderate daytime temperatures.

Appearance: Early symptoms of rust infection are yellow flecks or spots on either side of leaf. These develop into small, brick-red pustules that break through the surface (epidermis) (see Plate 29 on page 279). The brick-red colour is the result of spores being released from these oval or elongated lesions (2–10 mm (1–4 in.) long). Yellowing of the leaf occurs around these lesions. Dead, brown (necrotic) areas of the leaf develop, and in severe cases the entire leaf dies. The brick-red spores mature and turn black as they mature, causing the lesions and leaf surface to appear black.

Management Strategies: Since common rust does not survive in Ontario, cultural practices such as reduced tillage and crop rotation do not influence disease development. Commercial corn hybrids have good tolerance, whereas many seed corn inbreds, sweet corn and speciality corn hybrids are very susceptible to the disease. Foliar fungicides in field corn are not usually needed but can be economical in highly susceptible seed corn inbreds or specialty corn hybrids.

Common Smut

Incidence: Two corn smut diseases, common and head smut, occur in Ontario with common smut occurring most frequently. In severe cases, over 25% of the plants in some fields can have smut galls.

Appearance: Common smut overwinters, not only in the soil but in corn residue as well. The spores are spread by wind and rain through splashing. All above-ground plant tissue is susceptible, but infection occurs most often in areas of actively growing tissue. Common smut incidence increases in fields where the plants have been wounded by hail, frost, drought, mechanical injury, detasselling, herbicide injury, insects or sandblasting. High levels of nitrogen and manure promote this disease.

Greyish smut galls up to 10 cm (4 in.) in diameter develop on the stalks, ears and tassels, while smaller galls often appear on the leaves (see Plate 30 on page 279). The galls initially have a white membrane cover that eventually breaks and releases dark-brown or black powdery spores. On the leaves, galls develop into a hard, dry growth. Smut galls can replace kernels. Unlike common smut, head smut occurs on the ears or tassels (or both) only (see Plate 31 on page 279).

Disease Cycle: Spores released from the galls are well adapted for Ontario conditions. They survive in soil and crop residues for many years. In the spring, these spores germinate to produce new spores that will infect the rapidly growing areas or injured areas of the plant. The resulting galls will release spores that infect other plants. Disease development is favoured by rain showers, high humidity and warm temperatures.

Management Strategies: Most corn hybrids have enough resistance to smut to prevent serious outbreaks, however, some smut is present in most fields. Reduce your risk by minimizing mechanical and herbicide injury while maintaining a balanced fertility program. Rotation and cultivation have little affect on the disease since spores can survive for a long time in the soil.

Stalk Rots

Incidence: Fungi cause corn stalk rots, and the amount of damage they cause increases when the crop is under stress. Stresses that contribute to an increase in stalk rot infection include wet or dry conditions; cool evening and daytime temperatures; cloudy weather; leaf diseases (such as rust and Stewart's wilt); leaf and ear damage from hail, birds and frost; incomplete pollination; unbalanced fertility; insect damage (e.g., from European corn borer), high plant populations; hybrid susceptibility and poor soil conditions. All of these factors can increase a corn hybrid's susceptibility to stalk rots.

The distribution and prevalence of stalk and ear rot diseases vary from year to year, but the diseases are present in most years even though it may be at low levels. The majority of stalk rot damage in Ontario is caused by three fungi: *Anthracnose, Gibberella* and *Fusarium*, however, both *Diplodia* and *Pythium* have also been observed in Ontario. Refer to the sections below for more details on each of these stalk rot diseases.

Impact of Stalk Rot: Although these fungi cause different symptoms, their ultimate effect on the corn plant is the same; they reduce grain fill and stalk integrity and accelerate senescence. Stalk rot fungi affect the nutrient movement of the corn plant in three main ways.

1. Sugars (photosynthates) that would be produced through photosynthesis or carbohydrates in the root and stalk are diverted to the fungus and not to the ear. These nutrients allow stalk rot fungi to grow and flourish.
2. There is a reduction in stalk integrity. To meet the nutrient needs of both the developing ear and the stalk rot organisms, the corn plant will begin to cannibalize itself by moving soluble carbohydrates from the root and stalk. Problems arise when the plant is unable to meet the nutrient requirements of the developing ear and thus is forced to move more carbohydrates than usual. The result is a weaker stalk (prone to lodging) and less resistance to stalk rot fungi.

3. Finally, the infection and colonization process inhibits or blocks many of the pathways that the plant would ordinarily use to move nutrients. Yield losses (generally 10%–20%) arise from poorly filled ears and harvest losses from lodging.

Stalk Rot Management Strategies: Management begins by reducing crop stresses through:

- planting hybrids that have good resistance or tolerance to leaf diseases and stalk rots
- managing insects such as European corn borer
- good weed control
- appropriate plant populations
- a balanced N and K fertility program
- crop rotation
- tillage, etc.

Fields should be scouted to determine the amount of stalk rots present, and those fields that have 10%–15% of the stalks rotted should be harvested as early as possible. Crop rotation reduces the potential for stalk rots.

Scouting for Stalk Rots

Two methods or techniques are used to scout for stalk rots.

The Push Test

1. Randomly select 20 plants from five different areas of the field for a total of 100 plants.

2. As the name implies, push the top portion of the plant and note whether the plant lodged or not.

The Pinch or Squeeze Test

1. Randomly select 100 plants in the field (20 plants from five different locations).

2. Remove lower leaves and pinch or squeeze the stalk above the brace roots.

3. Record the number of rotted stalks.

If 10–15% of plants lodged, harvest the crop early. The extra drying charges that may result will be covered by increased harvest efficiencies with less corn left in the field.

Anthracnose Stalk Rot

Appearance: Anthracnose stalk rot is the easiest to identify. It appears as large, dark brown- to-black shiny areas or streaks on the outer stalk rind (see Plate 32 on page 279). These shiny or discoloured areas are often found at the base of the stalk. Cutting the stalk lengthwise will reveal a discoloured and rotted pith. Another symptom that is associated with this disease is "top dieback." Typically, top dieback symptoms begin in late August or early September as corn plants begin to wilt and die from the top down. Premature death occurs above the ear with the plant tissue below the ear remaining green. Examination of the stalk in these dead areas will show the same shiny black areas that are found at the stalk base. Plants with top dieback symptoms correspond to areas of the field that had late-season stresses.

Disease Cycle: The fungus that causes Anthracnose stalk rot survives in the previous corn crop residues and therefore is most often a problem in second-year corn. Warm, wet and humid weather favours anthracnose development.

Gibberella, Fusarium and Diplodia Stalk Rots

Appearance: These fungi all cause general stalk rot symptoms, include wilting and death. Affected leaves turn a grey-green colour, which resembles frost damage. All three rots cause a dark external lesion or spots at the lower nodes. Diplodia stalk rot produces small black spots (pycnidia) that are embedded in the stalk rind. These spots are hard to remove. This is in contrast to Gibberella stalk rot, which also produces small, round, black spots at the lower node, except these spots can be easily scraped from the stalk surface (see Plate 33 on page 279). The pith is shredded and has a pink to red colour. Fusarium stalk rot symptoms appear as light brown-to-black lesions near the nodes. The internal stalk symptom of Fusarium stalk rot is a salmon-pink fungal growth in the pith.

Disease Cycle: See the section *Ear Rots or Moulds*, on page 91, for each stalk rot disease.

Pythium Stalk Rot

Appearance and Disease Cycle: Pythium stalk rot gives the same general above-ground symptoms that are associated with the other stalk rot organisms. *Pythium* is in a unique group of fungi (that also includes *Phytophthora*) that are called "oomycetes" or "water moulds" because of their preference for wet conditions. The unique characteristic feature of this group of fungi is their production of mobile spores that can migrate or move through the water film in saturated soils. These spores (infection stage) are able to physically move to the corn plants roots and, once inside, cause disease. Corn plants infected with *Pythium* will not have any visible signs of fungal growth at the base of the plant that is different from the other stalk rots that produce overwintering structures (black dots) or mould. When the plant is cut lengthwise through the stalk base and roots, *Pythium*-infected tissue will appear wet and soggy and will disintegrate ("a wet rot") at the root base.

Ear Rots or Moulds

For detailed information on the incidence and disease cycles for each ear rot disease, refer to the sections below.

Ear Rot Management Strategies: White moulded corn may or may not contain toxins, but pink or purple moulded corn will likely be contaminated. Any of the *Fusarium* rots can establish after pollination in wounds created by insects or birds. Warm rainy weather or long dews any time after pollination may lead to ear rots in these wounded cobs.

The green (*Penicillium*) and black (*Cladosporium* or *Alternaria*) moulds do not normally pose a problem; however when found in great abundance, they may put livestock off feed. Development of ear rots is stopped when corn is dried or ensiled, but the level of harmful toxins already present will remain unchanged. Where corn is stored in cribs, these fungi will continue to grow under favourable weather conditions. The fungi will continue to produce toxin until corn moisture drops below 20%. See the OMAFRA Factsheet, *Controlling Fusarium Mycotoxicoses in Swine*, Order No. 90-066, or visit the Web site at www.gov.on.ca/OMAFRA/english/crops.

Preventing ear rots and mould is difficult since weather conditions are critical to disease development, and although some tolerant hybrids are available, none have complete resistance. Crop rotation can reduce the incidence of *Diplodia*. Cultural practices have been shown to have limited success in preventing ear and kernel rots. Minimize these diseases through timely harvest and proper drying and storage.

Harvest fields that have 10–15% stalk rot early. This will minimize losses due to stalk breakage or lodging.

When ear rot is present, the following storage and feeding precautions are advisable:

- Harvest as early as possible.
- If bird damage is evident, harvest outside damaged rows separately. Keep and handle the grain from these rows separately.
- Adjust harvest equipment to minimize damage to corn. Clean corn thoroughly to remove pieces of cob, small kernels and red dog.
- Cool the grain after drying.
- Clean bins before storing new grain.
- Check stored grain often for temperature, wet spots, insects and mould growth.
- Control storage insects.
- Exercise caution in feeding mouldy corn to livestock, especially to hogs. Pink or reddish moulds are particularly harmful. Suspect samples should be tested for toxins.
- Avoid cribbing corn with pink ear rot.

See Appendix F, *Laboratories Equipped for Feed Testing*, on page 262, for a list of laboratories.

Fusarium Ear Rot

Incidence: Fusarium ear rot is another common ear rot that occurs in Ontario. Unlike with *Gibberella*, *Fusarium*-infected kernels will be scattered around the cob among healthy-looking kernels or on kernels that have been damaged, for example, by corn borer or bird feeding. Silks are susceptible to infection during the first 5 days after initiation.

Appearance: *Fusarium* infection produces a white-to-pink or salmon-coloured mould (see Plate 35 on page 280). A "white streaking" or "star-bursting" can be seen on the infected kernel surface. Although many *Fusarium* species may be responsible for these symptoms, the primary species we are concerned about in Ontario is *Fusarium verticillioides* (formerly *Fusarium moniliforme*).

Disease Cycle: *Fusarium* survives in corn debris. The significance of this fungus is that it produces a toxin called fumonisin that has been shown to cause cancer (carcinogen) in humans. The environmental conditions that favour disease development are warm, wet weather 2–3 weeks after silking.

Gibberella Ear Rot

Incidence: The most common and important ear mould in Ontario is *Gibberella zeae*, which is the sexual reproductive stage of *Fusarium graminearum*. This fungus not only infects corn but also small grains such as wheat. Many plant pathologists believe that in years with a high occurrence of Fusarium head blight in wheat, the potential exists for increased Gibberella ear rot in corn.

Appearance: Although, the fungus can produce a white mould that makes it difficult to tell apart from Fusarium ear rot, the two can be distinguished easily when *Gibberella* produces its characteristic red or dark pink (purple) mould (see Plate 34 on page 279).

Disease Cycle: Infection begins through the silk channel and thus, in most cases starts at the ear tip. In severe cases, most of the ear may be covered with mould growth. Corn silks are most susceptible 2–10 days after initiation, and cool and wet weather during this period is ideal for infection.

Caution: Gibberella ear rot is economically important not only because of the potential yield and quality losses but because *Gibberella zeae* and *Fusarium graminearum* produce two very important mycotoxins that occur in Ontario — deoxynivalenol (vomitoxin or DON) and zearalenone. These mycotoxins are especially important to swine and other livestock producers since they can have a detrimental effect on their animals. Feed containing low levels of vomitoxin (1 ppm) can result in poor weight gain and feed refusal in swine. Zearalenone is an estrogen and causes reproductive problems such as infertility and abortion in livestock, especially swine. Feed grain that originated in a field with 5% or more Gibberella ear rot should be tested for these toxins. Refer to Appendix F, *Laboratories Equipped for Feed Testing*, on page 262, for a list of laboratories.

Diplodia Ear Rot

Incidence. Of the three primary ear rots that occur in Ontario, Diplodia ear rot is the least common. Diplodia ear rot is caused by *Diplodia maydis* and favours cool, wet conditions through grain fill.

Appearance: The characteristic ear symptom is a white mould that begins at the base of the ear and will eventually cover and rot the entire ear. Mould growth can also occur on the outer husk, which has small black bumps (pycnidia) embedded in the mould. These reproductive structures are where new spores are produced. Unlike *Gibberella* and *Fusarium*, *Diplodia* does not produce any known toxins.

Disease Cycle: Overwinters in corn debris left on the soil surface from the previous crop. Spores (conidia) that are produced during wet weather can infect silks and husks or enter through tissue damaged by birds or insects. Ears are most susceptible 3 weeks after.

Other Problems Affecting Corn Production

Cold

Early-Season Cold

Frost damage in May or June will generally have little impact on the crop, providing the growing point of the corn plant is still below the soil surface, which is the case until the young plant reaches roughly the sixth-leaf stage. On more advanced plants and/or where damage is more severe, split stalks to see if the growing point has been damaged. This procedure will require some time to make the correct recommendation as it probably takes 3–5 days following a frost to accurately determine the degree of damage, to verify the presence of healthy growing points (yellowish-white and firm) or to see new leaf growth.

In some cases, frozen leaf tissue, which bleaches to a straw colour several days after freezing, also develops a "knot," which may restrict expansion of the undamaged tissue lower in the whorl (see Plate 36 on page 280). Often it appears that clipping these knots by mowing the field aids in the plant's recovery. This is, however, mostly cosmetic. Tests conducted on frosted corn fields over the years have arrived at the conclusion that clipping appeared to help the fields "green up" but that unclipped sections of the same fields often recovered as quickly and yielded as much or more than the clipped sections.

There is very little that can be done to minimize the potential problem but here are some management factors that increase the risk of frost damage to corn should temperatures fall:

- inter-row cultivation
- side-dressing nitrogen (where soil is disturbed)

Table 3-28.
Estimated Risks to Grain Corn Yield and Quality Associated With Late Season Frost Damage

Crop Growth Stage	Frost Damage	Estimated Grain Yield Loss	Grain Quality Concerns
Mid-dough	Complete plant	40%	Severe
Mid-dough	Leaves only	25%	Severe
Early dent	Complete plant	25%	Moderate
Early dent	Leaves only	15%	Moderate
Half milk line	Complete plant	10%	Minor
Half milk line	Leaves only	0–5%	None

Note: This table is meant as a guide; differences among hybrids, overall plant vigour at time of frost and subsequent temperatures will all affect final grain yield and quality.

- herbicide applications
- presence of weeds
- high levels of previous crop residue

If the forecast calls for a risk of frost, growers may elect to delay inter-row cultivation, nitrogen side-dressing or herbicide applications until warmer temperatures return. Soil disturbance at the surface introduces more air into the soil and insulates the corn plants from the heat of the soil mass, thus increasing the risk of frost damage. Similarly, crop residues and weeds act as a barrier for heat transfer from the soil to the corn plant. Also, dry soils are more prone to frost damage because they have a lower capacity to store heat during the day and thus less heat to transfer and protect the corn plant overnight.

Late-Season Cold

Cold temperatures during the grain filling period in August and September may inflict yield and quality losses. The extent of these losses depends on the developmental stage of the corn and the temperatures recorded.

As temperatures drop to 0°C (32°F), frost damage first occurs to the leaves of the corn plants. This damage will eliminate any further photosynthesis, reduce grain filling and often have a negative effect on stalk strength. However, as long as air temperatures do not fall below -2°C (28°F), stalk tissues will remain viable and stalk constituents will be mobilized to fill the ear as much as possible. If, on the other hand, temperatures fall below -2°C (28°F), both leaves and stalks may be damaged and no further photosynthesis or remobilization can occur. This will terminate grain filling, and kernel black layer will develop. Table 3-28, *Estimated Risks to Grain Corn Yield and Quality Associated With Late Season Frost Damage*, above, outlines the potential risks to yield and quality for grain corn experiencing different levels of frost damage.

Generally growers will recognize the early dent stage as being the cut-off point where corn can withstand frost damage to the leaves and still produce a reasonable grain yield. This stage is characterized by having kernels, at least in the lower half of the cob, showing small indentations in the crown of the kernel.

The other question regarding cold nights revolves around the corn crop's ability to continue grain filling after experiencing several cold nights but where no frost damage occurs. Dr. Thys Tollenaar of the University of Guelph has conducted research where he measured 50% reductions in photosynthesis and rate of grain filling due to cold nights of 2°C. However, when these plants were restored to higher temperature conditions, they resumed plant activities at rates similar to those plants that had never experienced the low temperatures. If cornfields can escape any serious frost damage during cold nights, grain filling should carry on once normal temperatures return.

In some situations, frost damage will preclude harvesting the crop as grain and will force the grower to consider harvesting it as silage. There are important issues surrounding the management of the silage crop as well. Following a frost, silage corn frozen before reaching the half milk line on the kernel may be too high in moisture to properly ensile. Ideally, in cases of frost, corn harvest should be delayed until the entire plant reaches the desired moisture content for ensiling.

Heat

Heat stress is different than drought stress. Corn can usually tolerate temperatures as high as 38°C (100°F) before injury occurs, as long as drought conditions are not present as well. Temperature and drought sensitivity varies by hybrid. Drought-tolerant hybrids may result in yield drag; they are likely not good choices for a normal growing season.

Flooding

Flooding stresses the plant by cutting off the supply of oxygen to the root system. Younger corn plants die if submerged in water for more than 5 days, especially in warmer weather conditions. If air temperatures are high, death may occur in only a few days, as plant processes are sped up and the need for a supply of oxygen to the roots is high. In cooler weather, submerged plants may live for up to a week. After the 8-leaf stage of corn, plants can tolerate being submerged in water for more than 8 days but may be more susceptible to disease and may experience limited root development while under water. Yield loss due to flooding is most substantial for plants submerged immediately before and during tasselling and silking. Plants in the vegetative growth stages of 10–16 leaves and/or during the grain filling period display little yield response to flooding.

Drought

The corn crop requires apporximately 50 cm of water to produce high yields. This can be supplied to the corn crop over the growing season from a combination of stored water in the soil, rainfall or irrigation.

Lack of water causes the leaves to wilt and the plant to turn a greyish colour (see Plate 1 on page 273 and Plate 37 on page 280). Corn is most susceptible to dry conditions during the tasselling-to-silking stage and may demonstrate yield loss if under stress at this time (see Figure 3-3, *Moisture Deficiency*, on page 95). During the later vegetative stages of growth (V8–V14), the plant may benefit from dry conditions, as it forces the more rapid downward growth of the roots. Drought conditions during silking can reduce pollination and a lack of silk emergence, while drought after silking may cause a reduction in grain fill.

Hail

Cornfields damaged by hail may experience a reduction in leaf surface area, bruising of the stalk and ear and, in serious incidences, stalk breakage (see Plate 38 on page 280). Yield loss due to hail is dependent on the stage of the crop at the time of the hail event and the level of defoliation. Yield loss is greatest when the corn is defoliated during tasselling. Younger plants may experience a delay in growth and development due to hail, but yield loss is usually minimal. Defoliation of plants near maturity tends to cause little yield loss. Refer to Table 3-29, *Estimated Percentage Corn Grain Yield Loss Due to Defoliation at Various Growth Stages*, on page 96, when making yield loss estimates due to hail damage. Hail damage may also provide an entry point for diseases such as smut.

Birds

Birds can damage emerging seedlings, however, the more serious damage occurs to grain in August and September (see Plate 39 on page 280). Birds eat the kernels off the cob, causing direct yield loss, and kernel damage may result in mould growth. Bird damage can be easily confused with seedling damage caused by black cutworms or ear damage caused by grasshoppers. Noisemakers, such as Av-alarms, propane cannons, exploding shotgun shells, the Phoenix Wailer and recordings of bird distress calls may be successful deterrents if more than one technique is used and their pattern is changed frequently. If crop damage due to birds or wildlife is substantial, contact your local Ministry of Natural Resources office for control options.

Herbicide Injury

All herbicides have the potential to cause crop injury. Some soil applied (preplant or preemergent) herbicides can be splashed up on the leaves to cause injury, or the roots can take up the herbicide. With post-emergent herbicide products, most injury results at or shortly after application. Spray from the target crop onto a neighbouring non-target crop can also cause injury when the non-target crop is susceptible to the herbicide being applied. Spray overlaps are also common places where crop injury from herbicides can occur.

Stage of growth, crop stress, weather conditions, variety, tank mix partners and adjuvants can all affect the amount and severity of crop injury. When the target crop is under stress, it is sometimes not able to metabolize the herbicide fast enough to avoid injury. The type of herbicide (mode of action) is a major factor in how herbicides affect crops. In general, while contact herbicide injury may look worse, systemic herbicides will have longer-lasting and more detrimental injury, which may be more severe to the crop. Always read the label for information on how to reduce the risk for herbicide injury.

For more information, see the OMAFRA Factsheet, *Herbicide Mode of Action Categories*, Order No. 00-061, or visit the OMAFRA Web site at www.gov.on.ca/OMAFRA/english/crops/.

Specific Types of Herbicide Injury

Refer to the OMAFRA Factsheet, *Herbicide Mode of Action Categories*, Order No. 00-061, or Publication 75, *Guide to Weed Control*, for herbicide trade names.

Dinitroaniline (e.g., trifluralin, pendimethalin)
Dinitroaniline injury on corn caused by high rates or slow breakdown is shown in Plate 40 on page 281. Short roots with thickened root tips or stunted top growth with purplish leaves are common symptoms.

Chloroacetamide (e.g., dimethenamid, flufenacet, s-metolachlor)
Plate 41 on page 281 displays chloroacetamide injury on corn. Leaves are shortened, puckered and the coleoptile is twisted, with the leaves unable to unfurl properly. Plant stress can reduce the plant metabolism and ability to breakdown herbicide and causes more injury.

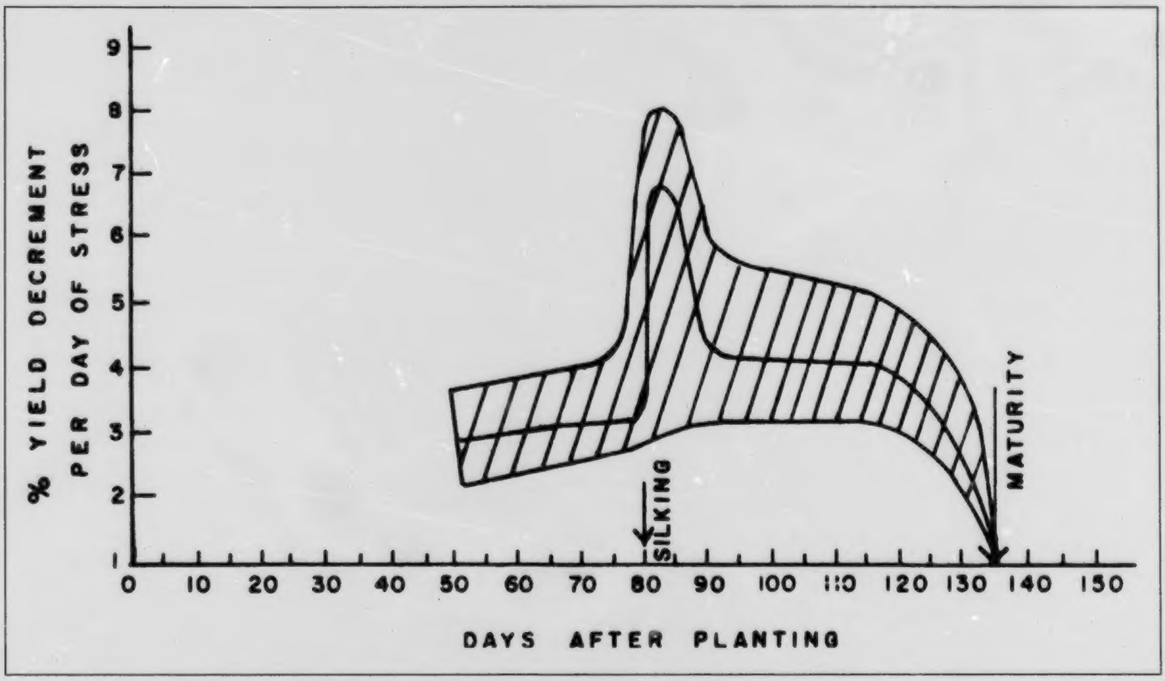


Figure 3–3.
Moisture Deficiency

Schematic diagram of the relationship between age of crop and percentage yield decrement due to 1 d of moisture stress. The top and bottom lines represent the highest and lowest yield reductions obtained in stress experiments, the middle line, the average reduction. Source: *Corn and Corn Improvement* (1988). Sprague and Dudley, editors.

Bleaching Herbicides (e.g., isoxaflutole, clomazone)

Plate 42 on page 281 shows bleached leaves on corn caused by isoxaflutole at high rates. Plants may emerge normally and then show symptoms at the 2–4-leaf stage. Symptoms may also occur after a rain. Leaves will appear yellow to white and are usually more pronounced near the midrib. Purpling may appear at the leaf margin or at the base of the whorl.

Auxinic Herbicides and Other Products Containing These Herbicides (e.g., 2,4-D, MCPA, dicamba, clopyralid)

Plate 43 on page 281 shows the "onion leaf" symptom on corn caused by high rates of dicamba (this can also occur on sensitive hybrids or when applied too late).

Dicamba injury causes twisted brace roots on corn (see Plate 44 on page 281). Brace roots are gnarled and tend to grow together and do not grow into the soil to support the plant, leading to potential lodging late in the season. High rates, sensitive hybrids or late applications can all cause these symptoms. Plate 45 on page 281 shows the effect on pollination when sprayed too late.

Bromoxynil

Plate 46 on page 282 shows bromoxynil injury on corn. Symptoms include a speckling of the leaf and browning on leaf tips and edges. Contact injury will show on leaves that are emerged at the time of treatment but not on new leaves emerging after treatment.

Acetolactase Synthase (ALS) and Other Products Containing These or Similar Herbicides (e.g., nicosulfuron, imazethapyr, chlorimuron-ethyl)

Sulfonylurea (ALS) injury on corn often appears as a "flash" on the leaf (see Plate 47 on page 282). Typically, corn outgrows this level of injury. Symptoms can include a yellow discolouration of the leaves, yellow flash on leaf (as shown), stunting of the plant, a delay in plant development and crinkled leaves or bleaching near the whorl. Onion-leafing or a purpling of stem or leaves may also occur. Some ALS herbicides may also reduce the root mass by shortening lateral roots. These herbicides should not be applied to corn that has been treated with an organophosphorus insecticide due to the increased risk of injury.

ACCase Inhibitors (e.g., sethoxdim, fluazifop-p-butyl, quizalofop-p-ethyl)

Group 1 graminicide (ACCase) injury on corn appears as intervenal chlorosis on newer leaves (see Plate 48 on page 282). Older leaves may show red or purple. The growing point turns brown and dies. The top of the plant can be easily pulled out of the whorl.

OTHER PROBLEMS AFFECTING CORN PRODUCTION

Table 3-29.
Estimated Percentage Corn Grain Yield Loss Due to Defoliation at Various Growth Stages[1]

	% Leaf Defoliation																		
	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Growth Stage[2]	% Yield Loss																		
7 leaf	0	0	0	0	0	0	1	1	2	3	4	4	5	5	6	7	8	9	9
8 leaf	0	0	0	0	0	1	1	2	3	4	5	5	6	6	7	8	9	10	11
9 leaf	0	0	0	1	1	2	2	3	4	5	6	6	7	7	9	10	11	12	13
10 leaf	0	0	0	1	2	3	4	5	6	7	8	8	9	9	11	13	14	15	16
11 leaf	0	0	1	1	2	3	5	6	7	8	9	10	11	12	14	16	18	20	22
12 leaf	0	0	1	2	3	4	5	7	9	10	11	13	15	16	18	20	23	26	28
13 leaf	0	1	1	2	3	4	6	8	10	11	13	15	17	19	22	25	28	31	34
14 leaf	0	1	2	3	4	6	8	10	13	15	17	20	22	25	28	32	36	40	44
15 leaf	1	1	2	3	5	7	9	12	15	17	20	23	26	30	34	38	42	46	51
16 leaf	1	2	3	4	6	8	11	14	18	20	23	27	31	36	40	44	49	55	61
17 leaf	2	3	4	5	7	9	13	17	21	24	28	32	37	43	48	53	59	65	72
18 leaf	2	3	5	7	9	11	15	19	24	28	33	38	44	50	56	62	69	76	84
19-21 leaf	3	4	6	8	11	14	18	22	27	32	38	43	51	57	64	71	79	87	96
Tassel	3	5	7	9	13	17	21	26	31	36	42	48	55	62	68	75	83	91	100
Silked	3	5	7	9	12	16	20	24	29	34	39	45	51	58	65	72	80	88	97
Silks brown	2	4	6	8	11	15	18	22	27	31	36	41	47	54	60	66	74	81	90
Pre-blister	2	3	5	7	10	13	16	20	24	28	32	37	43	49	54	60	66	73	81
Blister	2	3	5	7	10	13	16	19	22	26	30	34	39	45	50	55	60	66	73
Early milk	2	3	4	6	8	11	14	17	20	24	28	32	36	41	45	50	55	60	66
Milk	1	2	3	5	7	9	12	15	18	21	24	28	32	37	41	45	49	54	59
Late milk	1	2	3	4	6	8	10	12	15	18	21	24	28	32	35	38	42	46	50
Soft dough	1	1	2	2	4	6	8	10	12	14	17	20	23	26	29	32	35	38	41
Early dent	0	0	1	1	2	3	5	7	9	11	13	15	18	21	23	25	27	29	32
Dent	0	0	0	1	2	3	4	6	7	8	10	12	14	15	17	19	20	21	23
Late dent	0	0	0	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Nearly mature	0	0	0	0	0	0	0	0	1	2	3	4	5	5	6	6	7	7	8
Mature	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

[1] Adapted from the National Crop Insurance Services *Corn Loss Instruction* (Rev. 1994). Used with permission.

[2] As determined by counting leaves using the leaf over method (i.e., those with 40%-50% of leaf exposed from whorl and whose tip points below the horizontal).

New growth dies first, such that the plant appears to take considerable time to die after application.

Glufosinate Ammonium

Plate 49 on page 282 shows a susceptible corn plant injured by glufosinate ammonium herbicide adjacent to plants that are tolerant. Susceptible plants turn yellow and die. Injury occurs within the first few days after application.

Glyphosate Injury

Glyphosate drift on corn causes yellowing in whorl (some reddening on leaf edges) near the growing point. Leaves can become twisted, and plants will become stunted or die. Injury may take 1-2 weeks to develop and is not reversible.

4. Soybeans

Soybean acreage in Ontario has doubled in the past 10 years to over 809,000 ha (2 million ac). This represents more than a 2,000% increase over the past 50 years. The development of earlier maturity varieties, a wider selection of herbicides, improved yield stability, adaptability to no-till production and the relative low cost of production have contributed to this increase.

Expansion in the demand for specialty soybeans with identity preservation (e.g., food-grade, non-GMO, organic, etc.) has created new marketing opportunities for Ontario beyond the traditional end use of soybeans for oil production (i.e., crush) and livestock feed.

Tillage Options

The wide adaptation of soybeans to various tillage systems, particularly no-till, has contributed to rapid expansion in soybean acreage. Approximately 40% of the soybean crop is no-tilled, and 30% is planted with reduced tillage. Field experience and research trials have shown nearly identical yields between tillage systems. Management of the tillage system used is as important as the actual system selected.

Table 4-1.
Soybean Yield Response Under Various Tillage Systems[1]

	Row Width cm (in.)				
	Single 76 cm (30 in.)	Twin 76 cm (30 in.)	56 cm (22.5 in.)	38 cm (15 in.)	19 cm (7.5 in.)
Tillage	Soybean Yields t/ha (bu/ac)				
No-till	2.72 (40.4)	3.04 (45.3)	2.93 (43.6)	3.06 (45.5)	3.06 (45.5)
Fall moldboard	2.94 (43.8)	3.02 (44.9)	2.93 (43.6)	3.12 (46.4)	3.21 (47.7)
Fall zone-till	2.78 (41.3)	2.93 (43.6)	–	–	–
Spring zone-till	2.71 (40.3)	3.02 (45.0)	–	–	–
Least Significant Difference (P = 0.05) = 2.4[2]					

[1] Average of nine sites per year. University of Guelph (1998–2000). Trials were conducted on clay loam, silty-clay loam, silt loam and Guelph loam soil types. Spring zone-tillage conducted approximately 1 day prior to planting.

[2] Where the difference between two treatments exceeds 2.4, there is a less than 1 in 20 chance that it is due to random variation.

No-Till and Minimum Tillage

Ontario tillage research from 1997 to 2000 found that no-till soybean yields equalled the fall moldboard plow in twin rows and row widths 56 cm (22.5 in.) or less (see Table 4-1, *Soybean Yield Response Under Various Tillage Systems*, left). Although the yields are similar between the two tillage systems, no-till input costs are often lower and profit higher. Where single 76-cm (30-in.) rows were used, moldboard plowing produced the highest yields. When soybeans are planted in twin rows, soybean yields improve over 76-cm (30-in.) rows for all tillage systems. In this study, zone tillage has shown no significant yield improvement over no-till. Twin rows should be used in the spring zone-till system.

The greatest challenge in the adoption of minimum/no-till tillage is on heavy texture (clay, silty clay loam or silty clay) soil types. In some years, growers have reported reduced no-till soybean yields on these soil types compared to conventional tillage. Long-term tillage system research on Brookston clay soil at Ridgetown College, University of Guelph, resulted in equal soybean yields for no-till and fall moldboard tillage (see Table 4-2, *Soybean Yields for Ridgetown College 1992–2000*, below).

Table 4-2.
Soybean Yields for Ridgetown College 1992–2000

	Average Yield (excluding 1996)	
Tillage Treatment	t/ha	bu/ac
Fall moldboard plow	3.21 a	47.7 a
Fall chisel plow	3.05 b	45.4 b
Ridge tillage	2.96 b	44.1 b
Zone tillage	3.06 b	45.5 b
No-till	3.21 b	47.8 a
LSD (0.05)	2.2	2.2

Values followed by the same letter are not significantly different at the 5% level.

Table 4-3.
Effect of Tillage and Wheat Residue Management on Soybean Yields

Tillage (& Straw Management)	Soybean Yield t/ha	Soybean Yield bu/ac
Fall moldboard/straw baled	3.29	48.9
Fall chisel/straw baled	3.30	49.1
Fall disk/straw baled	3.21	47.8
Fall zone-till/straw baled	3.19	47.5
No-till/all straw and stubble remain	2.27	33.8
No-till/straw baled but stubble remains	3.00	44.7
No-till/straw baled and stubble removed	3.28	48.8

Average 1994-96, Centralia & Wyoming

Note: Stubble heights were approximately 20-30 cm (10-12 in.) except for plots where stubble was cut and removed. Soil types: Centralia: loam, clay loam. Wyoming: silty clay, silty clay-loam. Soybeans were seeded with JD 700 conservation planter equipped with a single 1.25 in. coulter. No-till planter was equipped with tine row cleaners.

Source: T. Vyn, G. Opuku and C. Swanton, University of Guelph

When soybeans follow a cereal crop, special attention must be paid to the management of cereal residue beginning at harvest to avoid problems with soybean establishment. The best action is to remove the straw and spread the chaff evenly. In research trials done by University of Guelph, removal of wheat straw improved seedbed conditions, stand establishment, growth and yield for no-till soybeans (see Table 4-3, *Effect of Tillage and Wheat Residue Management on Soybean Yields*, above). Cereal residue can form a mat that slows soil warming and drying in the spring. This can delay soybean planting, reduce soybean emergence and early growth, and lead to increased pressure from slugs. Minimum tillage in the fall or spring without the need for secondary tillage improves seedbed conditions and creates looser, finer soil to improve early soybean growth, while maintaining adequate residue to reduce erosion.

Tillage is best avoided along highly erodable knolls and slopes. In these situations, it may be prudent to use tillage only where the soil routinely remains cooler or wetter in the spring.

Crop Rotation Considerations

Soybeans are very responsive to crop rotation. Table 4-4, *Soybean Yield Response Under Various Crop Rotations*, right, presents the results of rotation studies conducted at Ridgetown College, University of Guelph. A rotation of soybeans, winter wheat and corn provided the greatest yield response. The continuous soybean rotation had the lowest yield. A short rotation leads to a build-up of disease and other long-term problems. Soybean cyst nematode (SCN) populations can increase rapidly, further reducing yields (see *Soybean Cyst Nematode*, on page 126). To reduce the incidence of white mould, maintain a 3-4 year rotation with other non-host crops. In fields with a history of Phytophthora root rot, a short rotation contributes to an increase in severity and number of races of the disease. The repeated use of Group 2 Herbicides-ALS inhibitors will encourage the spread of Group 2-resistant weeds.

Table 4-4.
Soybean Yield Response Under Various Crop Rotations

Crop Rotation	Soybean Yield t/ha	Soybean Yield bu/ac
Continuous soybeans	2.89	43
Corn, soybeans	3.09	46
Winter wheat, soybeans	3.23	48
Winter wheat, corn, soybeans	3.23	48

Ridgetown College/University of Guelph, 1997-2000.

Winter Wheat Following Soybeans

If winter wheat is to be grown following soybeans:

- Select a variety that requires about 100–200 heat units less than the number available in your area. Research from Ridgetown College, University of Guelph (1990–99), indicated that a variety requiring 100 CHUs less than a full-season variety advanced the maturity by an average of 5 days (range: 3–7 days). Going a further 100 CHUs less advanced the maturity 9 days compared to full-season varieties (see Table 4–5, *Soybean Maturity Dates for 2950, 3050 and 3150 Heat Unit Varieties*, on page 99).
- Plant the soybean crop early, as late planting will delay wheat planting.
- The wheat planting date can be calculated using the soybean planting date and the days to maturity of the soybean variety.
- Select a full-season soybean variety if broadcasting the winter wheat into a standing crop.
- Refer to winter wheat planting dates in the section *Planting Dates*, on page 183.

For more information on soybean crop rotations and precautions under different tillage systems, refer to the section *Crop Rotation*, on page 18.

Table 4-5. Soybean Maturity Dates for 2950, 3050 and 3150 Heat Unit Varieties[1]

		Soybean Maturity Dates[2]		
Year	Planting Date	2950 Heat Unit Variety	3050 Heat Unit Variety	3150 Heat Unit Variety
1990	May 28	Sept. 20	Sept. 25	Sept. 30
1991	May 11	Sept. 8	Sept. 13	Sept. 20
1992	May 15	Sept. 25	Sept. 27	Oct. 2
1993	May 20	Sept. 21	Sept. 26	Oct. 1
1994	May 27	Sept.14	Sept. 16	Sept. 21
1995	May 23	Sept.16	Sept. 18	Sept. 21
1997	May 23	Sept.17	Sept. 21	Sept. 27
1998	May 21	Sept.14	Sept. 17	Sept. 23
1999	May 12	Sept.10	Sept. 13	Sept. 19

Source: Ablett, Ridgetown College, University of Guelph.

[1] For 1990–99.

[2] These dates are for physiological maturity. Combining would be 3–10 days after these dates.

Variety Selection

There are over 200 soybean varieties, and their turnover in the marketplace is relatively quick. Aside from maturity and yield, variety selection should also be based on resistance or tolerance to disease, standability and soybean cyst nematode resistance.

Maturity and CHUs

Soybean development is affected by heat unit accumulation, day-length and hours of sunshine. Disease, moisture stress and other stresses can lengthen or shorten the actual days to maturity, depending on when the stress occurs.

Select a variety that corresponds to the heat unit rating for your farm (see Figure 3-1, *Crop Heat Units Available for Corn Production*, on page 57). Selecting full-season varieties will make maximum use of the growing season and offer the opportunity to maximize yield. However, when growing specialty soybeans such as the white hilum types, selecting shorter-season varieties will help ensure quality at harvest.

Hilum Colour

The hilum is the point at which the soybean seed attaches to the pod. Varieties differ in hilum colour and can be yellow (Y), imperfect yellow (IY), grey (GR), buff (BF), brown (BR), black (BL) or imperfect black (IBL). Yellow hilum soybeans are generally the preferred type for the export market. Hilum discolouration may occur on the imperfect yellow (IY) varieties. Affected beans may not be acceptable for export markets.

Choosing Superior Varieties

In addition to maturity rating, other factors of importance are yield potential, standability and insect and disease resistance. In selecting superior varieties, three main sources of information exist:

1) performance trial data
2) on-farm strip trial data
3) company information on characteristics of a variety

The Ontario Oil and Protein Seed Crop Committee conducts performance trials each year at various locations across the province. Results are published each fall in the *Ontario Soybean Variety Trials* brochure. This brochure is also available on the Internet at www.soybean.on.ca. These trials are valuable for comparing the yield potential of varieties. The trials also provide ratings for maturity, plant height and lodging. In Southwestern Ontario at locations with clay soil types, varieties are evaluated for resistance to Phytophthora root rot. Varieties with Phytophthora root rot-resistance are recommended on heavier soils. In fields with soybean cyst nematodes (SCN), varieties with SCN resistance should be included regularly in the rotation (see the section *Soybean Cyst Nematode*, on page 126).

On-farm strip trial information is useful in determining the adaptability of a variety over a wide range of conditions. Trial result summaries are provided by the Ontario Soil & Crop Improvement Association at their Web site (www.ontariosoilcrop.org). The performance trials and summaries of on-farm trials, where sufficient comparisons exist, are valuable tools for variety selection.

Seed companies will provide detailed information on growth characteristics of varieties to aid in selection. When evaluating variety performance, take into account that variety trials conducted under conventional tillage have proven to be a reliable indicator of a variety's performance under no-till conditions.

Select a variety with reduced lodging potential on soils with high residual nitrogen levels or on medium- to light-textured soils. If the soybeans are intended for on-farm livestock feed, a variety with a high protein index should be chosen.

Individual varieties may perform differently depending on growing conditions. Grow more than one variety to reduce the risk of total crop failure. Plant the majority of the acreage to proven varieties while testing new varieties on a smaller scale.

Identity-Preserved (IP) Varieties

Identity preservation is the segregation of a variety from planting through to delivery to an end user. It is not a new concept but has existed in a number of markets, including seed production and the production of food-grade soybeans. The introduction of genetically modified organisms (GMO) crop varieties has resulted in consumer demand for identity-preserved, non-GMO soybeans. The market offers various levels of premiums and contracts to the grower. The premiums offered for producing IP varieties need to be weighed against their increased costs, time and management. Limit the acreage planted to a size that can be harvested in a timely fashion. Performance information for some specialty-trait varieties may not be available. Data for these varieties may only be available from the company selling the seed and/or agreeing to take delivery of the crop after harvest. The agronomic qualities of an IP variety, such as yield, disease resistance and maturity should be evaluated to determine whether or not the premium offered upon sale is adequate. Performance trials of a number of food-grade soybeans are conducted by the Ontario Oil and Protein Seed Crop Committee. This information is available on the Ontario Soybean Growers Web site at www.soybean.on.ca. For crop insurance purposes, Agricorp provides a yield adjustment factor for a number of specialty soybeans.

Biotechnology

Varieties carrying special traits, such as resistance to certain herbicides, are now available in Ontario. These may have value for growers trying to address specific weed problems. They can also be useful in certain tillage systems. These varieties may not be accepted in all soybean markets.

Planting and Crop Development

Seed Quality

It is important to know the quality of the seed being planted. Certified seed must meet purity and germination standards. The quality of common seed is not known unless the germination is tested at an accredited seed lab prior to planting (see Appendix H, *Ontario Seed Laboratories Accredited by the Canadian Food Inspection Agency*, on page 263).

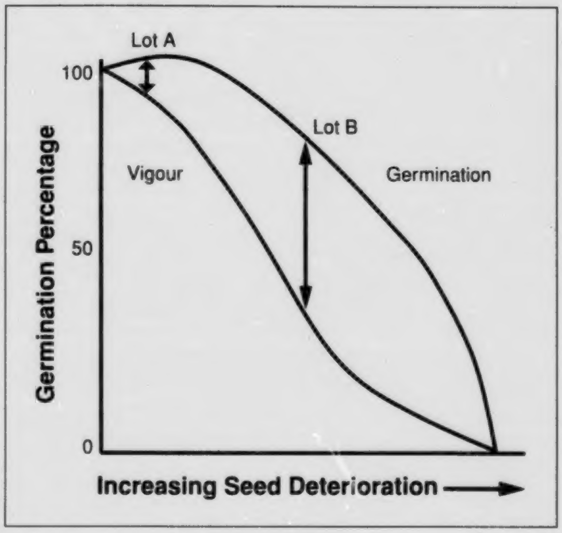


Figure 4-1.
The Relationship Between Seed Vigour, Viability and Deterioration

Source: Delouche and Caldwell, 1960

Germination is the major quality consideration used in grading seedlots. It is the ability of a seedlot to produce normal seedlings under favourable conditions of 95%–100% humidity and 25°C. Stress conditions in the field following planting often reduce field emergence compared to that in the lab.

A better measure of the ability of seed to emerge rapidly and uniformly under a wide range of conditions is the vigour rating of the seed, called the vigour test, or more appropriately referred to as a stress test. Certified seed standards require that seed be tested for germination. In addition to germination, many seed distributors routinely test and report seed vigour.

Figure 4-1, *The Relationship Between Seed Vigour, Viability and Deterioration*, above, illustrates the relationship between germination and vigour. As seed deterioration increases, germination drops slowly, whereas vigour drops very rapidly.

With Lot A, deterioration is minimal and germination and vigour are similar. On the other hand, Lot B has excellent germination but low vigour.

A number of factors can contribute to loss of seed vigour, including genetics, mechanical seed damage, deterioration in storage and weather conditions prior to harvest and disease. The most important factor affecting vigour appears to be environmental. Time-of-harvest studies conducted by the University of Guelph suggest that vigour is lost if there is a delay between physiological maturity and harvest.

Timely harvest is important if soybeans are being grown for seed.

Inoculation

Advancements in technology have provided inoculant types at a lower cost per acre, with higher rhizobia concentrations and more options for planting systems.

When soybeans are grown on land for the first time, inoculation with soybean rhizobia is essential for high yields. Sterile inoculants containing the bacteria strain 532C have been found to give a 7% yield advantage over other strains when soybeans are grown on virgin land. On non-virgin land, this advantage does not occur over other strains of inoculant bacteria. Use two different products or at least two different lots of the same product to improve chances of good inoculation.

A number of different types of soybean inoculants are available. Performance trials comparing inoculants are conducted each year by the University of Guelph. Table 4-6, *Increase in Yield From Inoculating First-Time Soybean Fields With Different Types of Soybean Inoculants*, right, presents a summary of 1998–2000 trials conducted in first-time soybean fields that revealed that liquid inoculants applied as in-furrow sprays or dribbled into the seed furrow at planting produced the highest yields. This application method involves equipping the planter or drill with nozzles or tips at each shoe plus a pressurized tank for the liquid inoculant. All major inoculant companies now market liquid inoculants.

Liquid inoculants applied to the seed prior to planting have also given good performance. Apply the inoculant at the base of a brush auger when loading the planter. Kits that hang on the side of a truck, tote or gravity wagon are available from dealers. Some manufacturers recommend that under very dry soil conditions, it may be good insurance when using a liquid inoculant to add a half-rate powdered peat for rhizobia protection. Occasionally, some growers have experienced bridging in the planter or build-up in augers from over-application of liquid seed treatments or inoculants. One option to reduce bridging is to apply a low rate of peat inoculant at the same time. Minimizing the time between treatment and planting by mixing in the field will also help.

Sterile-carrier inoculants use a powdered peat base that is sterilized prior to the addition of the inoculant strain. These inoculants carry much higher numbers of rhizobia than the older, conventional, non-sterile powdered peat. Non-sterile powdered peat often contains microbial contaminants, which may compete with the rhizobia.

Table 4-6.
Increase in Yield From Inoculating First-Time Soybean Fields With Different Types of Soybean Inoculants

Type of Inoculant	Yield t/ha (bu/ac)	Percent Increase Over Uninoculated Control Yields[1]
Liquid in-furrow spray	3.02 (45)	29
Liquid seed-applied	2.96 (44)	26
Sterile-carrier powdered peat	2.89 (43)	23
Granular inoculant	2.96 (44)	26
Non-sterile powdered peat	2.76 (41)	18
Control	2.35 (35)	-

Source: University of Guelph

[1] Values are from seven replicated field trials conducted near Guelph during 1996–2000. All sites were selected to be free of soybean rhizobia.

Granular inoculants are also non-sterile. They outperform non-sterile powdered peat inoculants because of the higher rate of granular inoculant applied per hectare.

Seed treatments may negatively impact inoculant performance. When using inoculants and seed treatments together, only treat the amount of seed expected to be planted within 4 hr of treatment. Trials show that only 40% of the bacteria survive after 4 hr.

Inoculant is not required where a well-nodulated, dark-green soybean crop has been grown in the past. Exceptions are acid soils (pH below 6.0) and coarse, sandy soils. Under these conditions, inoculation is recommended for each soybean crop. A grower who is not certain that previous soybean crops were well nodulated should inoculate to avoid the possibility of poor nodulation. Long-term trials indicate a 0.05–0.07 t/ha (¾–1 bu/ac) yield increase by inoculating soybeans planted into fields that have previously grown well-nodulated soybeans. Even in the absence of a soybean crop, soybean rhizobia will survive in most soils for 7–10 yr.

Recent studies have not shown any success in attempting to replace existing strains of rhizobia with newer, more-effective strains. Manure applied to soybean fields supplies a readily available supply of nitrogen, which soybeans will use over that provided by the rhizobia. In these fields, nodulation may be delayed, but yields will not be reduced. On virgin soybean ground where manure is applied, nodulation

Table 4–7.
Effect of Planting Date on Yield, Plant Height and Maturity

Planting Date	Yield (bu/ac)	Plant Height (cm)	Days to Maturity
May 10	54	109	137
May 24	48	112	125
June 3	47	112	119
June 13	44	93	112

Source: Ablett, Ridgetown College, University of Guelph, 1980–81

may not occur, and unless soil nitrogen is abundant, nitrogen deficiency may be observed

Soybean roots normally become infected with *Rhizobium japonicum* shortly after emergence. Nodulation of soybeans may be observed 3–4 weeks after planting. Checking fields at this point will allow time for nitrogen application, should an inoculant failure occur. In virgin fields, nodules will be located on the taproot. In previous soybean fields, nodules will also be found along lateral roots. Eight to 14 nodules per plant indicates adequate nodulation.

Planting Date

The highest yields of soybeans are obtained from early plantings, generally the first 10 days of May in the southwest part of the province. Later plantings are likely to incur significant reductions in yield (see Table 4–7, *Effect of Planting Date on Yield, Plant Height and Maturity*, above). Generally, if soil temperature and moisture conditions are suitable for planting corn, they are also suitable for planting soybeans.

> **Avoid planting soybeans at soil temperatures below 10°C (50°F).** Normally there is a 2-hr delay between air temperature and tilled soil temperature at seeding depth. Absorption of cold water by newly planted soybean seed may result in reduced germination and low vigour.

A hard spring frost can kill early-planted soybeans, since the growing point of the emerged seedling is above the soil surface. However, soybean plants can withstand temperatures as low as –2.8°C (27°F) for a short period of time, while corn experiences tissue damage at –2°C (28.4°F).

Delayed Planting

When planting is delayed, fewer days are required for the plant to reach maturity. A one-month delay in planting results in a 9-day delay at maturity. Delayed planting can reduce the vegetative growth period. This results in shorter plants with lower pods. Late planting also reduces the number of pods per plant because of the shorter flowering period. In addition, planting date has some effect on the duration of the pod-filling period.

> A 3-day delay in planting date generally results in a 1-day delay in maturity.

When planting is delayed beyond June 15, reduce the estimate of heat units available for crop growth by 100–150 for each week up to June 30. When planting after July 1, select a full-season, light-hilum variety (an early frost may cause dark hilums to "bleed" into the soybean).

Vegetative growth of late plantings can be improved by selecting taller varieties and planting in narrow rows. Seeding rates should be increased by 10%. This will increase the height of the lowest pods as well as the number of pods per acre.

Double Cropping Soybeans

Occasionally, a small number of soybean growers in the southernmost regions of Ontario have attempted to grow soybeans immediately following the harvest of their winter cereal or pea crop. Unfortunately, double cropping of soybeans in Ontario is more often a failure than a success. Do *not* take out a good red clover stand to double crop. The benefits from the clover stand will outweigh the risk involved in a double crop venture. Double cropping should not be attempted if soybean cyst nematode is a problem in the field. The soybean crop will reduce the benefits of the non-host (winter cereal) crop and increase cyst populations.

The following management tips will increase the chances of a successful double crop:

- At harvest, leave approximately 20 cm (8 in.) of stubble to promote soybean stem elongation and higher pod set.
- Plant immediately after a timely cereal or pea harvest.
- Plant 1 cm ($^1/_2$ in.) into moisture, but do not plant deeper than 7.5 cm (3 in.).
- Select tall, clear-hilum, full-season varieties if possible.
- Plant in narrow rows using high seeding rates.

Row Width

Soybeans grow well under a wide range of row widths in the long-season regions of Ontario. The choice of row width depends on factors such as tillage system, equip-

Table 4-8.
Row Spacing vs. Days to Full Canopy
(May Planting)

	Days to Full Canopy	
Row Spacing	**Planting Before May 15**	**Planting After May 15**
18 cm (7 in.)	30	25
38 cm (15 in.)	45	40
51 cm (20 in.)	55	50
76 cm (30 in.)	70	65

ment suitability, weed problems, experience, soil conditions, white mould pressure and planting date.

Wide rows allow for inter-row cultivation and are less affected by soil crusting. Narrow rows allow the crop canopy to fill in more quickly, providing maximum light interception (see Table 4-8, *Row Spacing vs. Days to Full Canopy (May Planting)*, above). Quick canopy development also contributes to weed suppression.

On heavier soil types such as clays, wider row widths increase the number of seeds per foot of row, which can aid in emergence. Improved air movement in wider rows may help reduce the severity of white mould.

The increase in yield potential from growing soybeans in narrow rows is greatest in the short-season areas. The yield advantage decreases towards Southwestern Ontario. Row widths of 18 cm (7 in.) are recommended in short-season areas. In Southwestern Ontario, there may be some advantage in reducing row widths to less than 53 cm (21 in.), as noted in Table 4-9, *Effect of Row Width on Yield*, right.

Seeding Rates

Soybean seeding rate is less critical than with corn. Soybeans can compensate considerably for differences in stands without effecting yield. Too high a seeding rate adds unnecessary seed costs and may increase lodging.

Seed-size differences impact seeding rates. Seed size and seed quality of a variety are influenced by growing and harvest weather of the previous year. There can be as much as 20% variation in the seed size of a variety from one year to the next.

Seeding rates listed in Table 4-10, *Recommended Soybean Seeding Rates*, on page 104, will provide satisfactory stands if 90% of the seeds emerge. Seeding rate must be adjusted upward for seed with a lower germination or vigour rating or for soils that tend to crust.

Table 4-9.
Effect of Row Width on Yield[1]

Soybean Row Width	Yield
18 cm (7 in.)	3.3 t/ha (49 bu/ac)
36 cm (14 in.)	3.2 t/ha (47 bu/ac)
53 cm (21 in.)	3.0 t/ha (45 bu/ac)
71 cm (28 in.)	2.7 t/ha (40 bu/ac)

[1] Values based on research on clay loam soils in the 3,250-CHU area. Greater response can be anticipated in shorter-season regions. The response to row-width reductions is reduced under stressful growing conditions.

Soybean varieties more prone to lodging will benefit from plant populations slightly lower than those given in the table.

Planting rates should be increased by 10%–20% with late plantings into mid-June. Varieties respond similarly to changes in seeding rate. The formula for determining seeds needed per foot of row is:

$$\text{Seeds needed per m (ft) of row} = \frac{\text{Desired final plant population per m (ft) of row}}{\text{\% germination x \% expected emergence}}$$

Planting Depth

A uniform seeding depth is important. Due to the high water demand for germination, plant 1 cm (approximately $^1/_2$ in.) into moisture but not deeper than 7.5 cm (3 in.). However, this is difficult to achieve with some seed drills, especially in reduced or no-till fields. Adequate down pressure, ballast and the use of a coulter cart can help achieve proper seeding depth. It is important to have good seed-to-soil contact and a closed seed slot. The key is to plant into adequate soil moisture with a properly adjusted planter/drill. If seeding into moisture with a drill cannot be achieved, consideration should be given to seeding with the planter, rather than waiting for rain.

Varieties differ in their ability to emerge from planting depths greater than 5 cm (2 in.). Seed companies typically provide an "emergence score" or hypocotyl length rating, which rates the ability of the seedling to emerge from unusually deep planting.

Soil Crusting

Crusting of the soil surface following a driving rain or water ponding can inhibit soybean emergence. The crust can break the hypocotyl arch (the portion of the plant that lifts the cotyledons above the soil surface).

Table 4–10.
Recommended Soybean Seeding Rates

		Row Width cm (in.)			
		18[1] (7)	36[2] (14)	53[3] (21)	71[4] (28)
		# of Seeds/M of Row (per ft of row)			
		10 (3)	18 (6)	22 (6.7)	29 (9)
Seeds/ Kilogram	Seeds/ Pound	Seeding Rate kg/ha (lb/ac)			
4,400	2,000	126 (112)	105 (94)	97 (87)	94 (84)
4,600	2,100	120 (107)	100 (89)	93 (83)	90 (80)
4,900	2,200	114 (102)	95 (85)	88 (79)	85 (76)
5,100	2,300	109 (97)	91 (81)	85 (76)	82 (73)
5,300	2,400	104 (93)	87 (78)	82 (73)	78 (70)
5,500	2,500	101 (90)	84 (75)	78 (70)	75 (67)
5,700	2,600	96 (86)	81 (72)	75 (67)	73 (65)
6,000	2,700	93 (83)	77 (69)	72 (64)	69 (62)
6,200	2,800	90 (80)	75 (67)	69 (62)	67 (60)
6,400	2,900	86 (77)	72 (64)	67 (60)	65 (58)
6,600	3,000	86 (75)	69 (62)	65 (58)	63 (56)
6,800	3,100	81 (72)	67 (60)	63 (56)	60 (54)
7,100	3,200	78 (70)	65 (58)	60 (54)	59 (53)
7,300	3,300	76 (68)	64 (57)	59 (53)	57 (51)

[1] Calculations for an 18-cm (7-in.) row width are based on a stand of 445,000 plants/ha (180,000 plants/ac).

[2] Calculations for a 36-cm (14-in.) row width are based on a stand of 400,000 plants/ha (160,000 plants/ac).

[3] Calculations for a 53-cm (21-in.) row width are based on a stand of 400,000 plants/ha (140,000 plants/ac).

[4] Calculations for a 71-cm (28-in.) row width and wider are based on a stand of 325,000 plants/ha (132,000 plants/ac). Final plant stand is based on 90% germination x 90% emergence.

If soil is prone to crusting, plan to break the crust before the seedlings are attempting to break through.

Light tillage with a rotary hoe, harrows, coulter cart or even the planter or seed drill can help break the soil crust and aid bean emergence. Typically these operations can cause a 10% loss of emerged beans. A higher stand loss can occur when the hypocotyl arch is breaking the surface. "Crust-busting" may not be necessary in thin stands (e.g., 60%) where full yield potential already exists. Refer to Table 4–11, *Expected Yield of Soybeans in Optimum and Reduced Stands*, right, to determine yield potential.

Plant Development

Table 4–12, *Vegetative Growth Stages in Soybean*, on page 105, and Table 4–13, *Reproductive Growth Stages in Soybean*, on page 106, show the growth stages of the soybean.

Table 4–11.
Expected Yield of Soybeans in Optimum and Reduced Stands[1]

% of Full Stand	Expected Final Yield as % of Optimum	Plants Per Hectare			
		18-cm rows (7-in.)	36-cm rows (14-in.)	53-cm rows (21-in.)	76-cm rows (30-in.)
100	100	553,300	402,600	392,700	405,100
80	100	442,100	323,600	313,700	323,600
60	100	331,000	242,100	237,100	244,500
40	87	222,300	160,600	158,100	163,000
20	62	111,200	81,500	79,000	81,500

1 hectare = 2.47 acres

[1] Conducted at Huron and Kemptville, Ontario, research stations, University of Guelph.

The first two leaves of the soybean plant are unifoliates (single leaflets) occurring opposite each other at the first node above the cotyledons. Subsequent leaves are trifoliate (three leaflets) and are on alternate sides along the stem. When the plant has 2–3 trifoliates, the nodules, which are important for the fixation of atmospheric nitrogen, become visible on the roots.

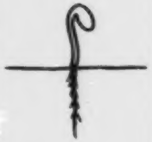
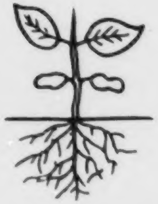
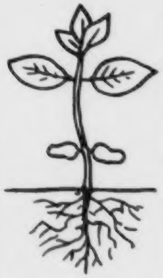
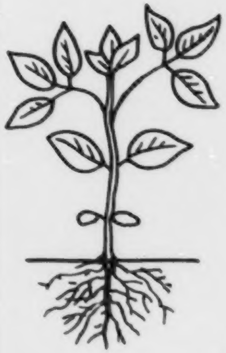
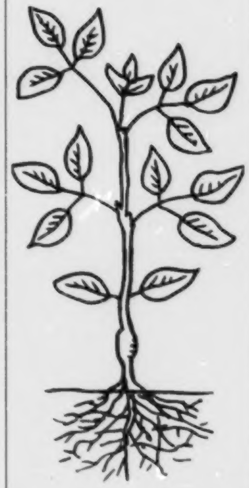
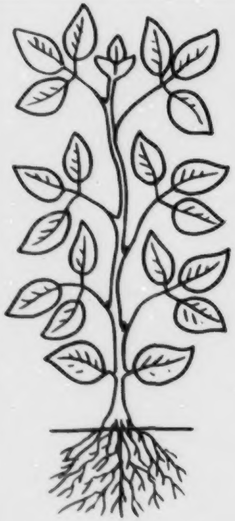
When planted at the optimal time, soybeans will develop 5–8 leaves before flowering begins. Flowering is triggered mainly by day length and temperature changes. Very early-maturing soybeans are nearly insensitive to day length. Instead, flowering is controlled mainly by accumulated heat units. Later-maturing varieties are influenced more by day length. Therefore, late-planted, long-season soybeans take fewer days to mature than those planted early.

Most commercial soybean varieties in Ontario are indeterminate. They continue to grow taller and produce new leaves after flowering has commenced. A small number of soybean varieties in Ontario are tall determinates. These varieties grow to their full height before flowering begins. The flowering process occurs over a shorter period of time. Tall-determinate varieties characteristically have their lowest pods higher off the ground than indeterminate varieties.

Germination and Emergence

Germination begins with the seed absorbing soil moisture until it reaches a moisture content of about 50%. The first external sign of germination is the emergence of the radicle (primary root), which grows downward and anchors itself in the soil. Shortly after, the hypocotyl (the section of the stem above the radicle) starts growing upwards, pulling the cotyledons (seed leaves) with it.

Table 4-12. Vegetative Growth Stages in Soybean
(Not all V stages are presented here.)

						
Stage Abbreviated[1]	VE	VC	V1	V3	V5	Vn
Stage Title	Emergence	Cotyledon	First Node	Third Node	Fifth Node	Node n
Trifoliate Leaves	0	0	1	3	5	n
Days to Achieve Stage[2]	10	5	~ 5 days/fully expanded trifoliate leaf			~3 days/trifoliate leaf (V6–Vn)
Range in Days[3]	5–15	3–10	3–10	3–10	3–10	
Notes	• Seedlings emerge from soil. • Emergence can be hindered by soil crusting.	• Hypocotyl straightens, and cotyledons unfold. • Unifoliate leaves open. • Growing point is above soil surface. • Frost can kill the plant. • Stem severed below the cotyledons will kill the plant.	• First fully developed trifoliate leaf unfolds at first node. • Start of critical weed-free period.	• Trifoliate leaves at 3 nodes. • End of critical weed-free period. • Nitrogen fixation begins at a slow rate.	• Trifoliate leaves at 5 nodes. • 50% leaf loss has little impact on final yield. • Early maturity soybeans reach R1 at approx. V4.	• No. of nodes to develop is function of maturity rating, planting date, climatic conditions.

[1] V refers to the vegetative stages of soybean development. Vn = number of nodes on the main stem with fully developed leaves beginning with the unifoliate node. A fully developed leaf is defined as one that has a leaf above it (at the next node) with an unrolled leaf.

[2] An estimate of the number of days required to move from one stage to the next.

[3] Range is an estimate of days within a specific stage of development and is influenced by planting date, maturity rating and climatic conditions and can vary considerably within and between seasons.

SOYBEANS

Table 4-13. Reproductive Growth Stages in Soybean

When evaluating a field of soybeans, each vegetative (V) or reproductive (R) stage is reached when 50% or more of the plants are at or beyond that stage.

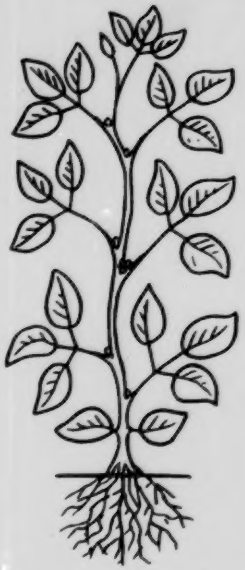
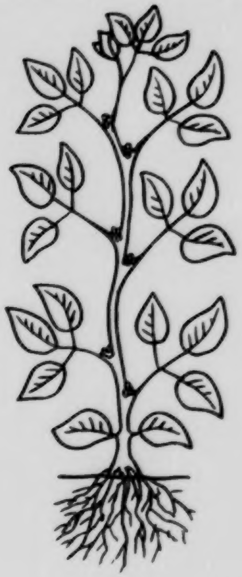
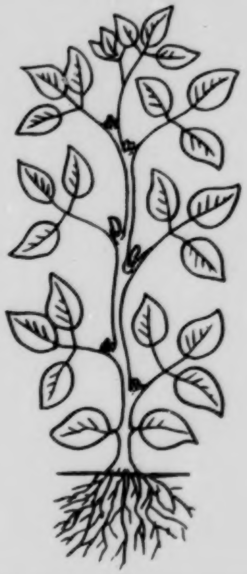
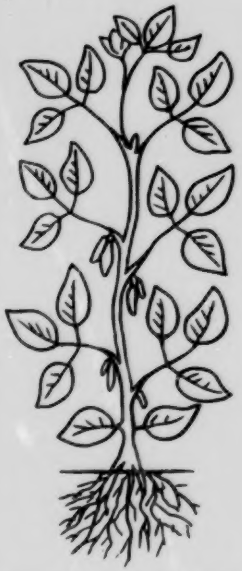
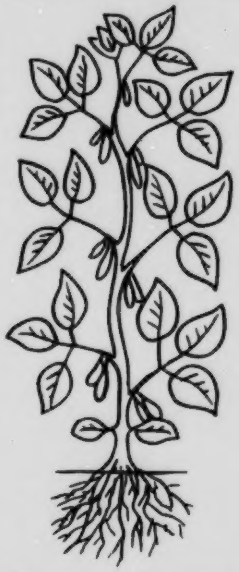
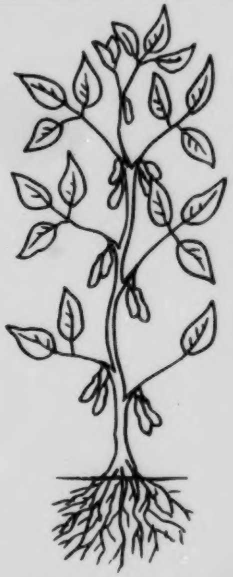
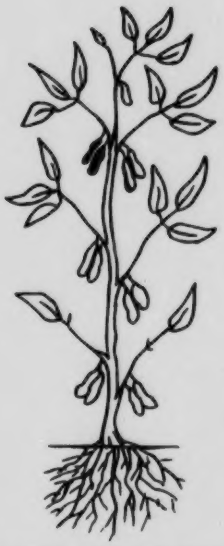
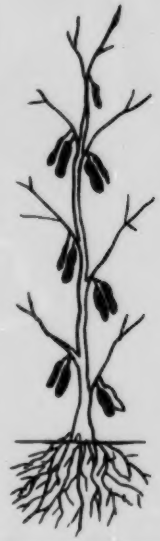
				
R Stage[1]	**R1 – Beginning Bloom** One open flower visible from any node on stem.	**R2 – Full Bloom** Open flowers at highest nodes of main stem.	**R3 – Beginning Pod** Short pods visible at upper nodes of main stem with fully developed leaves.	**R4 – Full Pod** Pods 2 cm (.75 in.) long at upper nodes of main stem.
Coinciding V Stage[2]	V4–V7	V5–V10	V8–V13	V11–V16
Days to Achieve Stage[3]	3	8	10	10
Range of Days[4]	1–10	3–15	4–22	6–25
Target Event	Flowering	Flowering	Pod Development	Pod Development
Notes	• Triggered by changing day length and temperature. • Flowering begins near node 5 (V4) and moves up and down the stem. • Root growth rates increase. • Extreme heat (i.e., over 32°C) can reduce growth, flowering and pod development.	• 50% height and dry weight accumulation. • Stress does not usually reduce yield. • Nitrogen fixation increasing rapidly.	• Look for 2–3 seeds per pod. • Flowering peaks.	• Stress occurring between R4–R6 can result in significant yield loss.

Table 4–13. Reproductive Growth Stages in Soybean (Continued)

				
R Stage[1]	**R5 – Beginning Seed** Seed .3 cm long within upper pods.	**R6 – Full Seed** Seeds within pods fill cavity in the upper pods.	**R7 – Beginning Maturity** One major pod has changed to brown colour on the main stem.	**R8 – Full Maturity** 95% of pods have changed to brown colour.
Coinciding V Stage[2]	V14–V19	V17–V21		
Days to Achieve Stage[3]	14	27	7	
Range of Days[4]	10–22	20–40	1–30	
Target Event	Seed Development	Seed Development	Plant Maturity	Plant Maturity
Notes	• Flowering completed except for some branches. • Plant reaches max. height, nodes and leaf area. • Nitrogen fixation rates reach max. and begin to decline. • Rapid nutrient uptake and redistribution to pods.	• Pods reaching full length. • Root growth slows substantially. • Above-ground dry weight accumulation slows. • Rapid leaf yellowing begins. • Leaves in lower canopy begin to fall.	• Moisture begins to decline in seeds. • Physiological maturity reached, maximum dry weight. • Seed moisture is about 60%.	• Harvest moisture reached in 1–2 weeks after R8.

[1] R refers to the various reproductive stages of soybean development.

[2] In Ontario, where the majority of soybeans grown are indeterminate in habit, vegetative and reproductive stages of development overlap for much of the plants' development.

[3] An estimate of the number of days required to move from one stage to the next.

[4] Range is an estimate of days within a specific stage of development and is influenced by planting date, maturity rating and climatic conditions, and can vary considerably within and between seasons.

PLANTING AND CROP DEVELOPMENT

Plate 50 on page 282 shows the hypocotyl straightening and the cotyledons unfolding from VE to VC.

Once emerged, the hook-shaped hypocotyl straightens out, the cotyledons fold down and the growing point is exposed to sunlight. Emergence normally occurs about 4–14 days after planting, depending on soil moisture, soil temperature and planting depth.

Replant Decisions

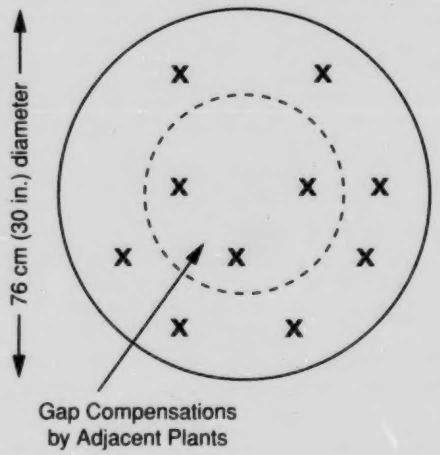
Assessment of a poor soybean stand should not occur too quickly. Fields with a plant reduction of 50% do not need to be replanted if plant loss is uniform and the stand is healthy. Every year, soybean stands are replanted needlessly. Numerous studies and field experience have demonstrated that keeping an existing stand was often far more profitable than replanting. Replanting gives no guarantee of a perfect stand.

There is no formula on which to base a replant decision. Every decision is based on factors surrounding individual situations. Information needed to make a replant decision includes:

- The population and health of the existing stand. Normal seeding rates include a margin of safety to ensure emergence of an adequate stand.
- The cause of the low plant population. A number of factors can cause reduced soybean stands. These include soil crusting, herbicide injury, frost, hail, insects and diseases. For instance, in a wet year, damping-off is likely to be caused by two fungal classes — *Pythium* and *Phytophthora*. In this situation, if the stand is to be replanted, the use of a *Phytophthora*-resistant variety plus a seed treatment should be considered.
- The uniformity of the remaining plant stand.
- The yield potential of the existing stand compared to the yield potential of a replanted stand. Yield potential begins to decline after the optimum planting date and declines throughout June (see Table 4–7, *Effect of Planting Date on Yield, Plant Height and Maturity*, on page 102).
- The costs of replanting and possibly additional weed control costs in thin stands.

Compensation and Plant Spacing (Gaps)

Soybean plants have an amazing ability to compensate for thin stands. Soybean plants can fill interplant spaces up to about 30 cm (12 in.) within or between rows without any yield loss, provided weeds do not compete for this space. Ontario research has found that a 33% reduction in the stand (distributed uniformly over the field) will not significantly affect yield.



On June 15, a reduced stand of solid seeded (18-cm rows) soybeans had an average 10 healthy plants per hoop (measured using a 76 cm (30 in.) diameter hula hoop). This equates to a population of 222,220 (10 x 22,222 plants per hectare) (see Table 1–3, *Determining Plant and Pest Populations Using a "Hula" Hoop*, on page 3). The yield potential of this stand is 90% of a full stand (see Table 4–11, *Expected Yield of Soybeans in Optimum and Reduced Stands*, on page 104). Replanting is not justified due to lower yield potential and higher cost.

FIGURE 4–2.
Reduced Stand in the Field

Plants in thin stands branch profusely, making them heavy and more prone to lodging. Branched plants tend to bear more of their pods near the ground. Consequently, harvest losses can be slightly higher in these stands. In trials with thin stands, lodging did not become a problem until populations dropped below 60% of a full stand. Stand reduction is rarely uniform.

Evaluating Stand Reductions

It is important not to make a quick decision about replanting. Accurately assess the stand for the population, spacing and health of the remaining plants. To determine plant population, refer to the hula-hoop method mentioned in the section *Determining Plant Population and Pest Infestation Levels*, on page 2.

Table 4–11, *Expected Yield of Soybeans in Optimum and Reduced Stands*, on page 104, provides an estimate of the yield potential compared to a full stand, based on research conducted in Ontario. It is important to note that this table is based on the number of healthy plants remaining in a thin stand spaced uniformly and kept free of weed competition. See, also, Figure 4–2, *Reduced Stand in the Field*, above.

Table 4–14.
Phosphate and Potash Recommendations for Soybeans Based on OMAFRA-Accredited Soil Tests

Sodium Bicarbonate Phosphorus Soil Test (ppm)	Rating	Phosphate (P_2O_5)[1] Required kg/ha	Ammonium Acetate Potassium Soil Test (ppm)	Rating	Potash (K_2O)[1] Required kg/ ha
0–3	LOW	80	0–15	LOW	120
4–5		60	16–30		110
6–7		50	31–45		90
8–9		40	46–60		80
10–12	MEDIUM	30	61–80	MEDIUM	60
13–15		20	81–100		40
16–30	HIGH	0	101–120		30
31–60	VERY HIGH	0	121–150	HIGH	0
61 +	EXCESSIVE[2]	0	151–250	VERY HIGH	0
			251+	EXCESSIVE[2]	0

100 kg/ha = 90 lb/ac

[1] Where manure is applied, reduce fertilizer applications according to the amount and quality of manure (see the section *Manure*, on page 20). Example of fertilizer application: If a soybean crop is not manured, and the soil tests are 9 for phosphorus and 85 for potassium, the phosphate requirement is 40 kg/ha and the potash requirement 40 kg/ha (see above). These nutrients can be supplied by broadcasting or banding 200 kg/ha 0-20-20 fertilizer.

[2] For a nutrient that has an excessive rating by soil analysis, the application of this nutrient in fertilizer or manure may cause problems due to reduced crop yield or quality. Phosphate additions may jeopardize water quality. Potash additions may induce magnesium deficiency on soils low in magnesium.

Evaluating Returns From Replanting

The numbers in Table 4–11 are used to determine the percentage yield for a field that was planted on time but suffers some stand reduction. This yield potential will only be realized if the plants remaining in the field remain healthy and free of weeds. Compare the potential return of leaving this stand to the returns from a delayed replanting.

Patching or Thickening Thin Stands

In cases of poor stand establishment, replanting alongside the established seedlings to patch up or thicken the existing stand seldom improves yields. Repair planting often leads to timing difficulties with weed control and harvest date. When dealing with unacceptably thin stands, significant yield improvement was only achieved when the original soybean stand was so poor that it had to be destroyed and a new stand re-established.

Fertility

Nitrogen

Nitrogen fertilizers are not usually required for soybeans. (See the section *Inoculation*, on page 101*)*. Research into nitrogen fertilizer applied at planting time has shown that nitrogen, even in small amounts, can delay nodule fixation.

If nodulation does not occur, and the soybeans are pale green and N-deficient, the recommended remedial measure is to apply 50 kg/ha of N at first flower, as urea or calcium ammonium nitrate, when the foliage is dry.

Phosphate and Potash

Phosphate and potash recommendations for soybeans are given in Table 4–14, *Phosphate and Potash Recommendations for Soybeans Based on OMAFRA-Accredited Soil Tests*, above. Occasionally, potassium deficiency will appear in soybeans as yellowing or browning of margins in older leaves (see Plate 51 on page 282).

For information on the use of this table or if an OMAFRA-accredited soil test was not completed, refer to the section *Fertilizer Recommendations*, on page 31.

Methods of Application

Fertilizer should not be placed in contact with soybean seeds due to the sensitivity to fertilizer salts. Unlike corn, there is no yield advantage to this practice. The fertilizer may be broadcast and plowed down or worked into the soil either in the fall or spring. A planter with a separate attachment for fertilizer placement may also be used to place the fertilizer 5 cm (2 in.) to the side and 5 cm (2 in.) below the

**Table 4–15.
Interpretation of Plant Analysis for Soybeans**

Nutrient	Units	Critical Concentration[1]	Maximum Normal Concentration[2]
Nitrogen (N)	%	4.0	6.0
Phosphorus (P)	%	0.35	0.5
Potassium (K)	%	1.2	2.5
Calcium (Ca)	%	–	3.0
Magnesium (Mg)	%	0.10	1.0
Boron (B)	ppm	20.0	55.0
Copper (Cu)	ppm	4.0	30.0
Manganese (Mn)	ppm	14.0	100.0
Molybdenum (Mo)	ppm	0.5	5.0
Zinc (Zn)	ppm	12.0	80.0

Values apply to the top fully developed leaf (3 leaflets plus stem) at first flowering.

[1] Yield loss due to nutrient deficiency is expected with nutrient concentrations at or below the "critical" concentration.

[2] Maximum normal concentrations are more than adequate but do not necessarily cause toxicities.

seed. For further information, see Table 2–30, *Maximum Safe Rates of Nutrients*, on page 47.

Plant Analysis

For soybeans, sampling the top fully developed leaf (three leaflets plus stem) at first flowering is recommended. Refer to Table 4–15, *Interpretation of Plant Analysis for Soybeans*, above. For sampling at times other than first flower, samples should be taken from both deficient and healthy areas of the field for comparative purposes.

A soil sample should be taken from the same area and at the same time as a plant sample.

Refer also to the section *Plant Analysis*, on page 110.

Micronutrients

Manganese

Manganese is the only micronutrient deficiency diagnosed in soybeans in Ontario, although zinc deficiency may show up in the future where the surface soil has been lost by erosion.

The symptoms of manganese deficiency are upper leaves ranging from pale-green (slight deficiency) to almost white (severe deficiency) with green veins (see Plate 52 on page 283). Soil tests and plant analyses are useful in predicting where manganese deficiencies are likely to occur. Both are available at the OMAFRA-accredited laboratories listed in Appendix B, *Accredited Soil-Testing Laboratories in Ontario*, on page 257.

Correct the deficiency as soon as detected by spraying the foliage with 2 kg of actual manganese/ha from manganese sulphate (8 kg of manganese sulphate/ha) in 200 L of water. A "spreader-sticker" in the spray is recommended. If the deficiency is severe, a second spray may be beneficial.

> Caution should be taken when applying micronutrients with a sprayer that has been used to apply herbicides. Cleaning out the spray tank is essential for avoiding crop injury. See the section *Herbicide Injury*, on page 131, for more details.

Soil application is not a recommended method of applying manganese regardless of the source because of the large amounts required. Application of manganese chelates to the soil has resulted in yield reductions.

In general, beans will give a profitable response to manganese in the parts of the field where manganese deficiency is showing. There is no benefit to applying manganese to beans without deficiency symptoms.

Harvest and Storage

Minimize Harvest Losses

Soybeans are direct combined, preferably with a combine equipped with a floating flexible cutterbar and automatic header control. Soybeans can be harvested at moisture levels below 20%, but they must be stored at 14% moisture or lower.

Harvest losses and mechanical damage may be high when soybeans are harvested below 12% moisture. A loss of just 4 beans/900 cm^2 ($4/ft^2$) represents an overall loss of 67 kg/ha (1 bu/ac). Losses can be minimized if a ground speed of 4–5 km/h (2.4–3 mph) is maintained. The reel speed should be adjusted to crop conditions.

A floating cutterbar can be used to cut the soybean plants off closer to ground level. The combine fan should be adjusted to provide maximum air without blowing soybeans into the return elevator or out the back. The chaffer is adjusted to allow the fan to separate pods and stalks from the soybeans and the sieve to allow only soybeans through. These settings should be adjusted as the conditions of weather and soybeans change.

Header maintenance is important. Blades and guards must be sharp-edged to provide a ledger plate allowing quick cutting action and rapid movement into the header. Belting on the bat reel to sweep the beans in and/or the addition of an air reel for short crops provides rapid movement into the combine.

The majority of the losses occur at the header.

If soybean plants remain standing and uncut behind the header:

- check blades and guards
- consider reducing ground speed

Quality and Identity Preservation

Preharvest

If the soybean crop is intended for an identity-preserved (IP) market, special effort must be taken to maintain seed quality. Staining and mechanical damage are the main problems at harvest. Staining can occur from weeds, immature beans, dirt and dust. Mechanical damage can result in an entire load being rejected. Prior to harvest, combines, trucks, wagons and other handling equipment and bins must be thoroughly cleaned to prevent contamination. Scout and rogue fields for off types and other volunteer crops (e.g., corn). Check fencerows and roadsides for glass, metal, fence posts, etc. Harvesting must wait until soybean stems and weeds have dried down completely to avoid green staining of the seed. Weeds such as Eastern black nightshade and American pokeweed may have to be removed from the field before harvest or avoided by the combine.

Harvest and Storage

If a different crop or variety was just harvested, harvest a small area separately to ensure the combine is clean. This sample can be used to check moisture and combine set-up. Oversee custom harvesters to make sure equipment is ready to harvest. Keep a copy of the IP contract on hand to determine the quality parameters at harvest. IP harvesting starts later and ends sooner in the day than for commercial beans; otherwise staining *will* occur. Once contaminated, a combine is difficult to clean. It is best to harvest at moisture levels close to 14% to avoid the need for anything other than ambient air drying. Harvesting at or above 12% moisture, in addition to gentle handling, is necessary to avoid cracked seed coats. Adjust the combine to conditions throughout the day. Adjustments to reduce mechanical damage may increase dockage (pick) but is more than compensated for by premiums. IP soybeans should be stored in separate bins that are free from other soybean varieties and other grains and oilseeds. If the crop was produced under contract, many of these requirements may be outlined in the signed agreement. With or without a contract, failure to comply can result in lost premiums.

It is important to assess the quality of seed at harvest in order to make appropriate adjustments to the combining and seed-handling process to reduce further damage to the seed. See Figure 4-3, *Hypochlorite Soak Test for Soybeans*, on page 112, for a discussion of soybean seed coat damage.

Soybean Drying

Grain Dryers

The three basic general types of grain dryers used on the farm are:

1. in-bin
2. batch
3. continuous flow

These three broad groups can be further broken down into different types. No single drying system is superior to all others in every respect. System selection is dependent on desired features. These features include drying capacity, grain quality, fuel/drying efficiency (BTU/lb water removed), convenience, manpower required to run the dryer, ability to dry a variety of crops, maintenance required and capital cost.

All dryers move air past the grain to evaporate moisture from the grain and carry the water vapour away. Heat is added to this drying air to reduce its relative humidity, thereby increasing its ability to pick up moisture. Wet grain can be dried at higher temperatures since it will be cooled as the moisture evaporates from the kernels. As the grain dries, it will approach the temperature of the drying air. The longer the grain kernels are in contact with this heated air, the drier and hotter the kernels will get.

Drying Soybeans With Heated and Unheated Air

Soybeans are sometimes harvested at a higher moisture content due to wet weather or earlier than expected to reduce losses. All drying methods are adaptable to soybeans with some restrictions on the use of heat and handling practices.

Care must be taken when using heated air to dry tough soybeans — beans that are higher in moisture than desired for safe long-term storage. The relative humidity of the drying air must be kept above 40% to prevent seed coats from splitting. Experience has shown that with as little as five minutes exposure to high heat, it is possible to cause 100% of the soybeans to crack. Most recommendations for drying commercial soybeans suggest a maximum temperature of 55°C–60°C (131°F–140°F). In good drying weather, you may need to reduce this drying temperature to control seed

Hypochlorite Soak Test for Soybeans

Introduction

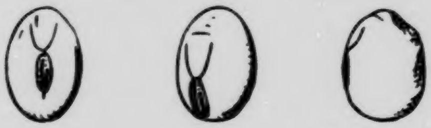
The soak test is a quick test to reveal soybean seed coat damage. The test is primarily used during harvest to help reduce mechanical damage due to combining and seed handling. Samples are tested in the field, and the appropriate adjustments are made to reduce damage to less than 10% damaged seeds. The test is also useful in determining processes that cause damage within the conditioning plant.

Procedures

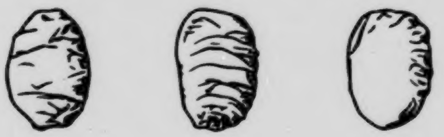
1. Prepare a 1:5 dilution of household bleach to water to obtain a 1% sodium hypochlorite solution. Note: Dilutions as low as 1:43 have been used.
2. Obtain several shallow plastic containers (similar to petri dishes) that will each hold 100 soybean seeds.
3. Take a random sample of seed. Count out four replicates of 100 seeds each, excluding splits and other obviously broken seeds. Place in plastic container. Note: A counting board can be made by drilling 100 quarter-inch holes in a 6.5 x .25 x 0.5 in. board.
4. Submerge each 100-seed replicate in the solution for 10 minutes.
5. Remove swollen seeds with tweezers.
6. Average the number of swollen seeds per replicate. If over 10%, adjust the combine or handling to reduce damage.

Evaluation

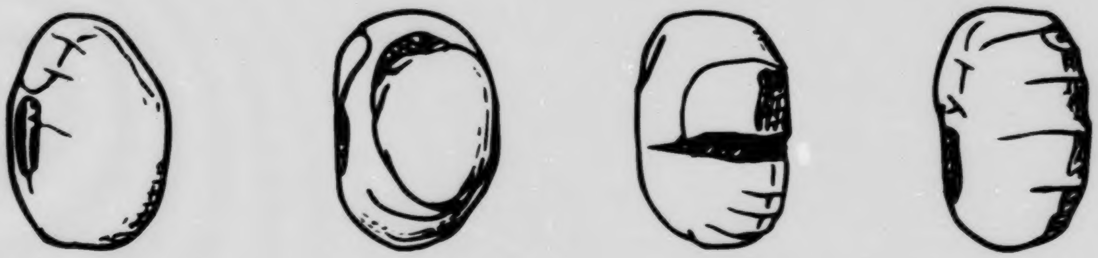
Seeds can usually be separated into three different categories following the 10-minute soak.



1. Firm seeds do not take up solution. These are considered to have little or no damage.



2. Wrinkled seeds take up a small amount of solution, which causes their seed coats to blister. These are only very slightly damaged.



3. Swollen seeds take up solution and appear nearly two to three times their original size. Some may have only a large water blister at one end, and others may be breaking apart. These seeds are considered damaged.

Figure 4-3.
Hypochlorite Soak Test for Soybeans

Source: Iowa State University of Science and Technology – Seed Testing Laboratory, Seed Science Centre 1992 coat cracking. Check the number of split seeds before and after drying to gauge the drying effect.

Seed soybeans should be dried at temperatures below 40°C (104°F). This should only be attempted after several years of experience. Some seed companies frown on the use of any heat in conditioning seed soybeans. Ask your seed company what method of conditioning tough seed beans it prefers.

With bin dryers, caution should be used in any system that involves moving the soybeans in the bin with recirculators or stirrators. Damage from handling can be severe, especially as the moisture content drops to 12%.

Natural-Air Drying

Do not run the fan continuously, night and day, as you will re-wet the soybeans at night. The progress you make during the daytime will be undone at night. Careful management of fan operation is critical for drying success.

Tough soybeans can be dried with natural air under good drying conditions. Natural-air drying of soybeans requires careful management by the operator since soybeans both give up and take on moisture easily. The fan must be run only when the outside conditions will result in drying progress.

Minimum Requirements for Natural-Air Drying

- Full aeration floor in the bin
- Level soybean surface across the whole bin
- Minimum airflow of 6.5 L/sec/m^3 (0.5 CFM/bu), preferably more
- Clean beans with no pods or fines accumulations
- Accurate moisture reading of the beans in the bin
- Accurate outside air temperature and relative humidity measurement
- An understanding of soybean equilibrium moisture content
- An on/off switch for the fan

A full aeration floor is essential to move air uniformly through the whole bin contents. With a partial aeration floor or air duct system, dead areas will exist, leading to potential spoilage problems. Bean pods, trash and fines accumulations in the bin will restrict or divert airflow. Air moving through the bean mass will take the path of least resistance.

Determining Airflow

Sufficient airflow is needed to move drying air through the whole bean mass. To remove moisture, the minimum airflow required is 6.5 L/sec/m^3 (0.5 CFM/bu). Anything less than 6.5 L/sec/m^3 will only change temperature but will not change moisture content of soybeans. Higher airflow rates of 26 L/sec/m^3 (2 CFM/bu) or greater, only gets the job done quicker. In order to determine the CFM/bu value for your bin, determine the number of bushels in the bin and the static pressure that the fan is operating against. A simple manometer connected to the air plenum below the perforated floor will show you the static pressure in inches of water column (see Appendix I, *Home-Built Manometer*, on page 265). Using your fan performance curve, you can find the fan output at the measured static pressure. Dividing the CFM output of the fan by the number of bushels in the bin will give you your CFM/bu airflow. If you cannot get adequate airflow, one strategy is to only partially fill the bin. This way, the fan will be operating at less static pressure and deliver higher airflow rates per bushel.

Table 4-16.
Equilibrium Moisture Content (% Wet Basis) for Soybeans Exposed to Air

Temperature		Relative Humidity (%)				
(°C)	(°F)	50	60	70	80	90
0	32	10.0	11.8	13.7	16.2	19.8
5	41	9.8	11.5	13.5	15.9	19.6
10	50	9.5	11.2	13.2	15.7	19.4
15	59	9.2	11.0	13.0	15.5	19.2
20	68	9.0	10.7	12.8	15.2	19.0
25	77	8.7	10.5	12.5	15.0	18.8

Equilibrium Moisture Content

Researchers have developed equilibrium moisture content tables that aid in predicting the final moisture content of soybeans when exposed to air at a certain temperature and relative humidity (see Table 4–16, *Equilibrium Moisture Content (% Wet Basis) for Soybeans Exposed to Air*, above). To determine, for example, the equilibrium moisture content of soybeans exposed to outside air at 10°C (50°F) and 70% relative humidity, find the point at which the 10°C (50°F) row and the 70% relative humidity column intersect. This point will be the equilibrium moisture content for soybeans at the outside air conditions stated. Given enough time, the soybeans will dry down to 13.2% moisture content.

Measuring Relative Humidity

Accurately measuring the relative humidity of the outside air presents a bit of a challenge. In some cases, this reading can be obtained from a nearby weather station. It is important to determine if this weather station is an accurate reflection of conditions at your location. To air-dry soybeans, you need to know, with accuracy, the relative humidity of the outside air. Do not use your household hygrometer to measure relative humidity for air-drying tough beans. These units tend to be inaccurate. It is recommended that you purchase a sling psychrometer or a good quality hygrometer for around $100.

When to Run the Fan

Fan operation is not limited by the time of day but rather by air temperature and relative humidity levels. On some days, drying can be accomplished from 9:00 am until midnight, while on others it may only be from 9:00 am to 6:00 pm. Check the temperature and relative humidity of the air numerous times throughout the day. The outside air needs to be drier than the inside air for making drying progress. If the equilibrium moisture content on a given day is less than the moisture content of the wettest beans, drying is possible, and the fan should be on. Humidistats are available that will activate the fan at pre-set humidity levels. The operator can adjust the relative humidity level at which the fan is activated.

The beans at the top of the bin will be the last to dry. Each day of fan operation will push a drying front up through the bin. This drying front may not reach the top of the bin as quickly as expected. Be sure to take your moisture samples at the same depth each time to know how the moisture content is changing at that depth. Bins with stirrators will have fairly uniform moisture levels throughout the whole bin.

Weed Control

Critical Period for Weed Control

> The critical period to control weeds in soybeans is from the 1st to 3rd trifoliate-leaf stage (V2–V3).

Yield loss caused by weeds can be reduced to less than 5% by maintaining good weed control during the critical period. Later-germinating weeds have a minimal impact on yields and have relatively low weed seed production.

The product label for postemergent herbicides indicates the growth stage of the weeds when optimum control can be obtained. The timing of weed control should optimize the critical period for the crop and the optimum growth stage of the weed.

Crop Losses Due to Weeds

Crop scouting is essential to determine the weed species present and their density and population in the field. Some weeds are more competitive than others. Table 4–17, *Soybean Yield Loss Due to Weeds at Known Populations,* on page 115, shows the comparative yield losses caused by different weed species.

Weed competitiveness should be considered when deciding whether to treat escapes. The estimates in Table 4–17 are based on normal weather conditions and adequate soil moisture. They also assume that the weeds emerged with the crop. Yield losses may increase under drier soil conditions and may be variable under conditions of plant stress.

The effects of weed populations on crop quality and harvest procedures also need to be considered. For example, Eastern black nightshade is not a big threat to yield but can have a severe effect on crop quality.

Herbicide Resistance

Herbicide-resistant weeds have been found in Ontario. Resistance to triazine herbicides was first found in 1974 and can now be found in several species of broadleaf weeds and grasses. In 1997, pigweed plants resistant to ALS (Group 2) herbicide were found. Most recently, in 2000, some Eastern black nightshade and common ragweed plants were found to be resistant to some ALS herbicides.

Herbicide resistance usually develops from repeated use of the same type of herbicide. Using principles of integrated weed management helps reduce the onset of resistance and manage resistance when it is found.

Integrated Weed Management

Weed control in the soybean crop is influenced by:

- crop rotation
- row width
- variety characteristics
- tillage practices

In general, the agronomic practices that produce a healthy, fast-growing crop will allow it to compete best with weeds.

Crop rotations can be effective in reducing certain perennial weeds. Rotating to soybeans can allow for different herbicides or tillage practices that are particularly effective on specific species. The use of burndown herbicides in no-till soybeans has been effective for controlling weeds such as quackgrass or thistle.

Narrow rows and higher plant populations can increase the crop canopy and reduce the growth of weeds. Take care to balance the benefits of weed control with other requirements of the crop. Early planting can help the crop establish a competitive canopy before the weeds. However, a key strategy for weed control in organic soybeans is the use of spring tillage to stimulate weed germination. This is followed by a tillage operation prior to planting to kill the first flush of weeds. This delays the date of planting and may therefore reduce yield. If inter-row cultivation is to be used, the row width must be wide enough to permit it.

Equipment can carry weed seeds from one field to another. Combines, tillage equipment and soil erosion can all transport weeds. Weeds can also infest a field from manure application or other soil amendments. Proper sanitation and cleaning of equipment along with maintenance of field border areas all affect long-term weed management in the field.

Please refer to OMAFRA Publication 75, *Guide to Weed Control*, for more information, including herbicide products and rates.

Table 4–17. Soybean Yield Loss Due to Weeds at Known Populations

Crop losses assume that the weeds emerge at the same time as the crop.

	Soybeans Crop Losses Due to Weeds (%)		
	1 plant/m^2	5 plants/m^2	25 plants/m^2
Annual Broadleaf Weeds			
Cocklebur	15	41	65
Eastern black nightshade[1]	14	40	64
Giant ragweed	14	40	64
Lamb's-quarters	13	38	63
Pigweed	12	36	62
Lamb's-quarters (atrazine resistant)	10	33	60
Ragweed	10	33	59
Pigweed (atrazine resistant)	9	30	58
Velvetleaf	6	23	51
Wild mustard	5	20	49
Lady's thumb	4	15	41
Wild buckwheat	4	15	41
Annual Grass Weeds			
Volunteer corn	4	15	41
Giant foxtail	3	12	36
Proso millet	3	12	36
Fall panicum	2	10	33
Barnyard grass	3	12	36
Green foxtail	2	8	29
Yellow foxtail	1	5	20
Old witch grass	1	4	18
Crabgrass	1	4	15
Perennial Weeds			
Canada thistle	5	20	49
Milkweed	5	20	49
Perennial sow-thistle	5	20	49
Quackgrass	4	18	45
Horsetail	3	12	36
Nut sedge	2	7	29

Adapted from Herbicide Application Decision Support System 2001.

[1] Eastern black nightshade losses are due to quality concerns.

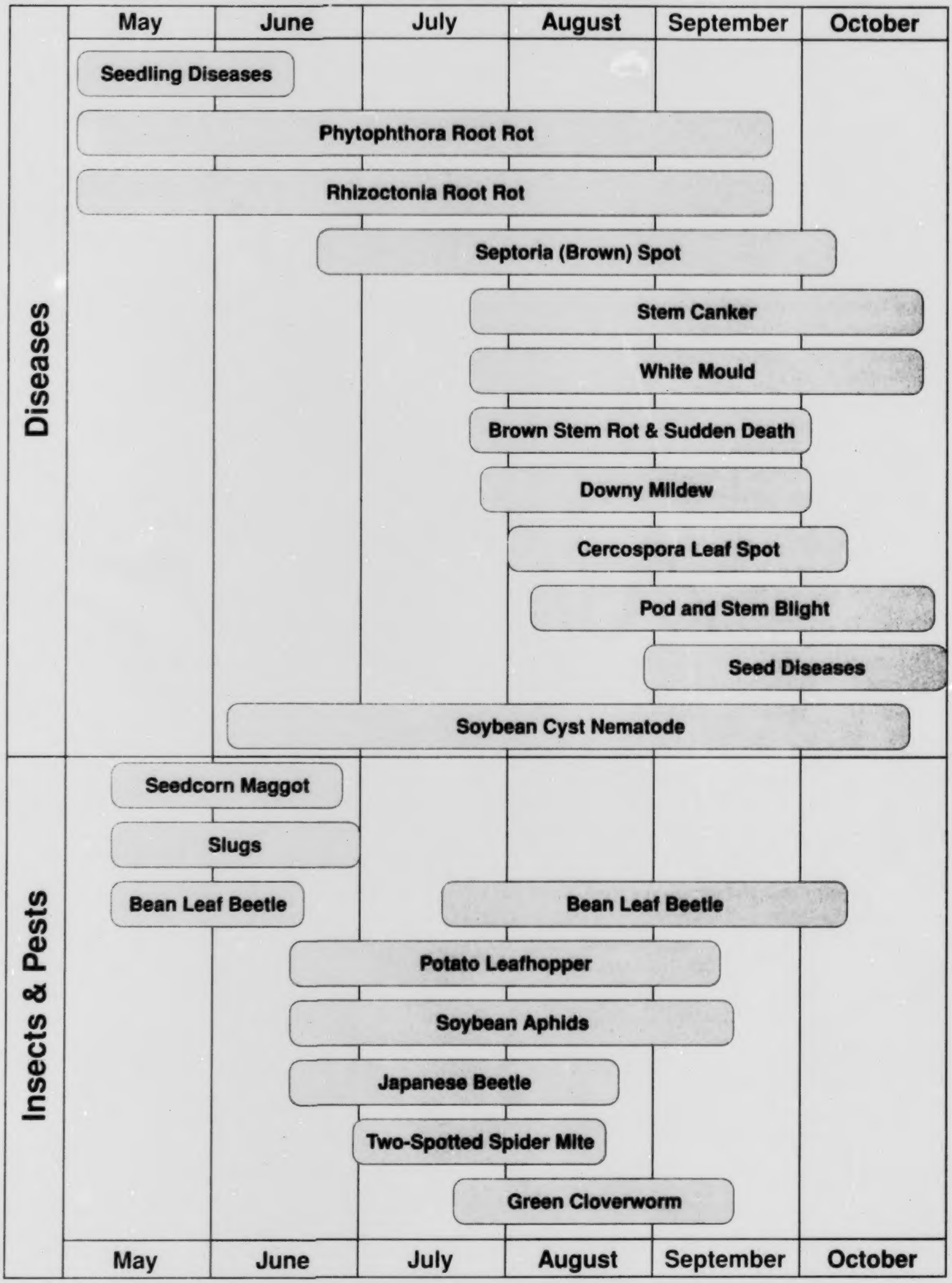


FIGURE 4-4.
Soybean Scouting Calendar

Insects

Table 4–18, *Symptoms in the Field*, below, shows insects and pests that could be causing the symptoms in the field.

Individual descriptions of insects and diseases found in soybeans and recommendations for their control follow.

Table 4–18.
Symptoms in the Field

	Insects and Pests							
Symptom	Bean Leaf Beetle	Grasshoppers	Japanese Beetle	Potato Leafhopper	Seedcorn Maggot	Slugs	Soybean Aphid	Two-Spotted Spider Mtie
Gaps in the Stand								
Tunelling into cotyledon, embryo or hypocotyl					x	x		
Holes in Leaves								
Ragged holes in leaf (looks like hail damage)						x		
Round holes in leaf	x	x	x					
Leaves Distorted or Discoloured								
Tips of leaves yellow or appear scorched				x				
Small white stipples on upper surface of leaves, leaves turning yellow								x
Leaves puckering or plant stunting (leaves may be sticky)							x	

Seedcorn Maggot

Description: The seedcorn maggot is a small, yellowish-white, headless, legless larva (see Plate 53 on page 283). The body tapers to the front with two small mouth hooks protracting. The maggots burrow into germinating seeds and the below-ground parts of emerging seedlings, producing weak seedlings. The adults resemble a small housefly that is slender, light grey and approximately 5 mm in length.

Life History: Seedcorn maggot adults (flies) will mate, and the female will search for an egg-laying site from April until the middle of June. The females are attracted to moist soils that give off an odour of decaying organic matter such as fresh crop residues, areas where manure has been applied or freshly tilled soil. Weeds are also attractive to females. The adults lay their eggs in the soil. The larvae then develop in the soil and organic residue, feeding on germinating seeds.

Damage: Seedcorn maggot is usually a problem during cool, wet springs when germination is delayed. The maggots feed on the swollen, ungerminated seed. They can be found in the cotyledon, embryo and hypocotyl. Slow emergence and/or reduced stand establishment can occur. Seedlings that escape and germinate often die or lag behind.

Scouting Technique: Unlike wireworm, seedcorn maggot damage is usually found over a generalized, large portion of the field. Nothing can be done to rescue a damaged field except replanting if necessary. High-risk factors include freshly tilled soil with heavy crop residue, recently applied manure, recently tilled green manure and deep planting, along with cool, backwards emergence conditions in the forecast.

Action Threshold: No thresholds are available at this time.

Management Strategies: Consider insecticide seed treatments in early-planted fields where large amounts of manure or residue have been recently incorporated or primary tillage has recently occurred. Use good-quality seed that will emerge quickly. See OMAFRA Publication 812, *Field Crop Protection Guide,* for recommended registered products. There are no rescue treatments available.

Slugs

Description: Juveniles and adults are soft-bodied, legless, greyish or mottled in appearance and have a slimy or gelatinous covering that helps keep them from drying out. The head has two pairs of tentacles. Slugs usually range from 1–3 cm in length but can reach up to 10 cm.

INSECTS

Life History: There is one generation per year but two populations, one maturing in spring and one maturing in fall. Therefore, both eggs and adults are found overwintering. Juvenile slugs hatch from eggs in the spring and the fall. They are active during cool and wet periods of the year. Slugs prefer environments with high humidity and relatively cool temperatures. Debris, such as crop litter or manure, provides them with shelter from the sun.

Damage: Slugs feed above or below ground, depending on the moisture level. They can feed on germinating seeds and seedlings with no real preference for a plant part (see Plate 54 on page 283). On larger plants, slugs feed on lower parts, eating partly or completely through leaves, leaving ragged holes causing a skeletonized appearance on leaves (see Plate 55 on page 283). Feeding damage can resemble that caused by hail, and severe defoliation can result. The main concern with slugs on seedlings is that they often feed on the growing point, and the seedlings cannot recover from this. Damage occurs April through October under wet weather. Slug damage is most severe during prolonged cool, wet weather in May and June. Higher-risk fields include those where no-till practices on soybeans are used for a continuous period of time and those with considerable crop residue. No-till soybeans following forages or cover crop are also high risk.

Scouting Technique: Scout for slugs at night or in the early morning hours, when they are active (nocturnal). Look for stripping of leaf tissue and/or small holes chewed in the leaves. Check under debris and clumps of soil. A certain sign of slugs is a slimy, silver-coloured trail on the plants or soil. Check 1.5 m of row in five locations in the field (under clods and pieces of plant residue).

Action Threshold: Prevention is the only action available.

Management Strategies: Tillage can be used against slugs, since the elimination of the crop cover exposes the slugs to dehydration and predation by birds and mammals. Zone tillage or row sweepers can help speed up the drying of the row area, thus deterring slug feeding. Moving trash away from seedlings may help to reduce damage. There are presently no economical and effective chemical methods available for slug control. Refer to OMAFRA Publication 812, *Field Crop Protection Guide,* for any future chemical control options.

Potato Leafhopper (PLH)

Description: Adults are pale-green, wedge-shaped, winged insects about 3 mm long with piercing and sucking mouth parts (see Plate 56 on page 283). Adults are broadest towards the head, the body tapering evenly to the wing tips. They have a row of six rounded, white spots behind their head. Nymphs are smaller than adults and are wingless.

Life History: PLH does not overwinter in Ontario. Leafhoppers generally migrate north every spring, carried along by southerly weather fronts that start in the Gulf of Mexico. Adults generally arrive by late spring, feeding first on alfalfa and other perennial legumes. PLH generally does not appear on beans until late June after alfalfa has been cut. Occasionally huge numbers of leafhoppers may arrive "overnight" from the south, resulting in a damaging population on seedling beans. Females lay their eggs in the main veins and petioles of the leaves. Development from egg to adult takes approximately 2–3 weeks.

Damage: PLH feed by piercing plant tissue and sucking plant sap. While doing this, they damage the vascular cells, which blocks the veins, causing plant nutrients and products to accumulate in the leaf. This causes the leaves to curl and pucker, and eventually the leaf edges begin to scorch. These symptoms are called hopperburn. Border rows are affected first. Yield is lost before hopperburn is seen, so do not use hopperburn as a management guide. Leafhoppers tend to come into soybean and edible bean fields after neighbouring alfalfa fields are cut. The symptoms of potato leafhopper are commonly confused with herbicide injury problems, nutrient deficiency and drought stress. High-risk factors include hot, drier-than-normal seasons.

Table 4–19.
PLH Thresholds for Edible Beans
(Adults and Nymphs)

Bean Growth Stage	PLH Threshold per Trifoliate
Unifoliate	0.25
Second trifoliate	0.5
Fourth trifoliate	1.0
First bloom	2.0

Action Thresholds: High PLH populations on hairy-leafed (pubescent) soybean varieties do not necessarily result in yield loss. On non-hairy soybean cultivars, use Table 4–19, *PLH Thresholds for Edible Beans (Adults and Nymphs)*, above, as a guideline for thresholds. Note: These thresholds are for edible beans.

Management Strategies: PLH generally do not cause significant injury to soybeans. Soybean varieties with high pubescence (hairiness) prevent the leafhoppers from feeding on the leaf tissue by creating a mechanical barrier, making it difficult for PLH to reach the leaf with their sucking mouthparts to feed. However, some varieties of soybeans, especially the food grade types, lack the hairs necessary to protect the plants against leafhoppers.

Soybean Aphid

Description: The soybean aphid is a small (pinhead-size), pale yellow aphid with black cornicles ("tailpipes") and a pale yellow tail (see Plate 57 on page 284). Adults may be winged or wingless. Nymphs are smaller than the adults and are wingless.

Life History: The soybean aphid, a pest originally from Asia, was first discovered in North America in 2000 and in Ontario in 2001. This insect has two primary hosts that it requires to complete its life cycle. The soybean aphid survives overwinter as eggs on the twigs of buckthorn species. In the spring, nymphs hatch from these eggs, and the aphids undergo two generations as wingless females on the buckthorn. The third generation develops into winged adults that migrate to soybean plants. The aphids then continue to produce wingless generations until the soybean plants become crowded with aphids and the plants experience a reduction in quality. Once crowded, winged forms are produced to disperse to more-crowded soybean plants. There can be as many as 18 generations of aphids per year. Like most aphids, the soybean aphids are all female, born pregnant and give birth to live nymphs. Males are only born in the fall so that the females and males can mate to produce the overwintering egg.

Damage: Aphids feed by piercing the plant tissue using a tube-like mouthpart and sucking the plant sap. Leaves on moderately to heavily infested plants will begin to pucker, curl and deform. Plants may become stunted. A reduction in pod and seed production may occur if aphid populations become extremely high. Aphid damage is more likely to cause yield reduction if the plants are already suffering from drought conditions or another stress factor. Aphids also excrete a sticky substance called honeydew, which can act as a substrate for grey sooty mould development. This insect may also vector soybean mosaic virus (see the section *Soybean Mosaic Virus*, on page 130). High-risk factors include fields under stress, which cause the plants to be less tolerant to the feeding damage.

Action Threshold: Thresholds are not available at this time.

Management Strategy: There are several natural enemies, including the ladybird beetle (ladybug) (see Plate 58 on page 284), pirate bug and syrphid fly larva that are helpful in controlling this pest. A pathogen can also infect the aphids but requires warm, moist conditions to become established. Refer to OMAFRA Publication 812, *Field Crop Protection Guide*, for recommended products. Insecticide is only warranted in extreme cases, as the insecticide will kill the natural enemies and can cause a rebound in the aphid populations.

Two-Spotted Spider Mite

Description: The adult mite is barely visible to the naked eye, approx. 0.5–1.0 mm in length, rounded, eight-legged and yellowish-brown with two dark spots on the sides of the abdomen (see Plate 59 on page 284). The larvae look like the adults but have six legs instead of eight. Two nymphal stages look similar to the adults, with four pairs of legs. Overwintering females are orange/red.

Life History: Spider mites generally overwinter as adult females in sheltered areas such as plant debris and field margins. Wheat fields underseeded to red-clover are another important overwintering site. Red clover provides food for mites until freeze-up, allowing the mites to survive right in the field. In late April as the weather turns warm, mites become active in search of food and egg-laying sites. Spider mites disperse by crawling, so infestations tend to spread slowly from field edges. Non-mated female mites will mass at the top of the plants and spin webs that serve as a "balloon" allowing strong winds to pick them up and carry them off to another site. Spider mite females can reproduce without mating. A single unmated female can be the start of a new colony. Under hot, dry, windy conditions, infestations can spread very quickly. There can be up to seven generations per year, with generation development overlapping. Frequent rain and cool weather reduce mite populations in soybeans.

Damage: Mites feed on individual plant cell contents on the underside of leaves through stylet-like mouthparts. Each feeding site causes a stipple. Severe stippling causes yellowing, curling and bronzing of the leaves (see Plate 60 on page 285). Upon close examination, fine webbing on lower surfaces of the foliage can be seen. Symptoms can be confused with water damage or herbicide injury along field borders. Damage is more severe in hot, dry weather and usually occurs in mid-July after winter wheat harvest. High-risk factors include neighbouring winter wheat stubble fields, hay fields and ditch banks and fencerows that harbour overwintering mites. No-till soybeans following winter wheat underseeded to red clover are also at risk.

Scouting Technique: Scout fields around the first week of July. Infestations usually move in from the edge of fields as hot spots. Look for tiny white stipples on the upper surface of leaves in the mid-canopy. Turn these leaves over and look for slow-moving dark specks (a 10X-hand lens may be necessary to see mites).

Action Threshold: Four or more mites per leaf or one severely damaged leaf per plant prior to pod fill is cause for concern.

Management Strategies: If mite numbers exceed the action threshold, an insecticide may be necessary. Refer to OMAFRA Publication 812, *Field Crop Protection Guide,* for recommended products. Early infestations may be kept under control by using border sprays. This will help prevent the spread of mites to other parts of the field and may reduce the need for further treatment. If rain is in the forecast, spraying should be delayed; prolonged wetness will usually reduce the number of mites to insignificant levels. Use of drought-tolerant varieties will minimize the effect of spider mites. Natural enemies help keep mites at low levels when conditions are unfavourable for the mites. Natural enemies of mites include ladybird beetles, thrips and predaceous mites. Cool temperatures and high humidity can promote a pathogen to develop that can also provide natural control.

Defoliating Insects

Soybeans are able to compensate for large amounts of foliage loss due to insect feeding, and often little effect on yield is observed. However, the most critical stage for soybeans is bloom to pod-fill, when seed development is highly dependent on photosynthesis. Should large amounts of defoliation occur at this stage, yield can be affected and, therefore, control may be necessary.

To estimate damage thresholds for leaf-feeding insects on soybeans, the percentage of defoliation occurring in each soybean field must be determined. In 10 areas of the field, pick trifoliate leaves from 5 plants that are newly and fully expanded from the center of the plant canopy. Discard the least and most damaged leaflets from each trifoliate collected. Compare the leaflets that are left with Figure 4-5, *Defoliation Chart for Soybean Leaf-Feeding Insects,* right, and determine the average percentage of defoliation.

Once the percentage of defoliation in each field has been established, general damage threshold guides can be used to determine whether control is necessary, depending on the stage of the crop (see Table 4-20, *Standard Damage Thresholds for Soybean Insect Defoliation,* below.)

Table 4-20.
Standard Damage Thresholds for Soybean Insect Defoliation

Soybean Development	% Defoliation
Pre-bloom (i.e., vegetative stages)	30%
Bloom to pod-fill	15%
Pod-fill to maturity (unless pod feeding observed)	25%

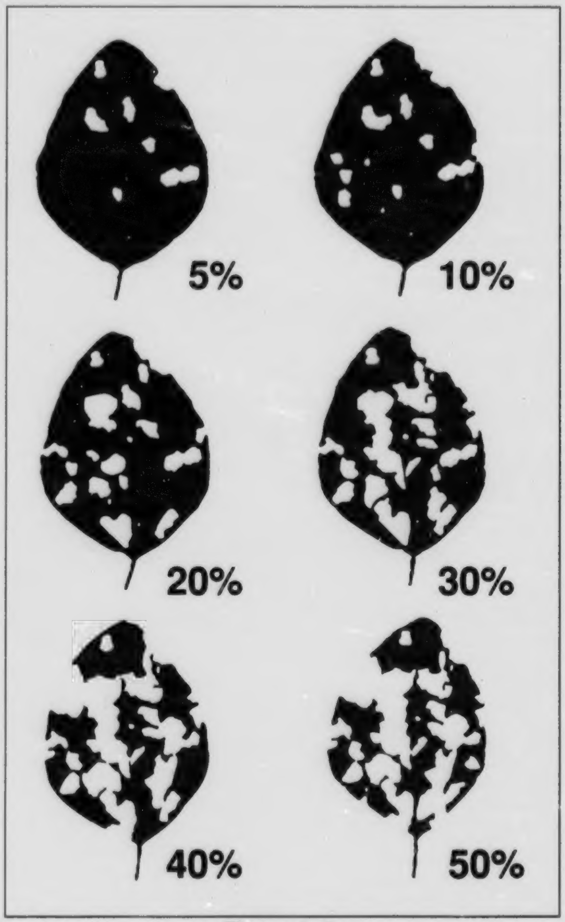


Figure 4-5.
Defoliation Chart for Soybean Leaf-Feeding Insects
Source: University of Illinois and Purdue University, 1982

Bean Leaf Beetle (BLB)

Description: The bean leaf beetle adult is around 5 mm in length (small) with four black spots usually found on the wing covers (see Plate 61 on page 285). Adult beetles can vary in colour but are most often yellow-green, tan or red. A small, black triangle is visible at the base of the wing covers (the prothorax — behind the head). The margins of the wing covers have a black border.

> The bean leaf beetle is often confused with the spotted cucumber beetle. A small black triangle is visible at the base of the wing covers (behind the head) of the bean leaf beetle.

Life History: There is only one generation of BLB per year. The BLB has recently been found to overwinter in Ontario after mild winters. It overwinters in the adult stage in woodlots, leaf litter and soil debris. In late April, the overwintering adults become active and begin feeding on nearby alfalfa fields until the first cutting of alfalfa or soybeans emerges. Mated females then lay lemon-shaped, orange-coloured eggs in small clusters in the soil at the base of the soybean plants. Egg-laying occurs until late June. Newly hatched larvae feed on roots and other underground plant parts for about 30 days before pupating. Adults emerge from the soil in late July and begin feeding on the soybean foliage and pods. Feeding continues until plants dry down for harvest, when BLB then migrate back to alfalfa fields, if available, or move to overwintering sites.

Damage: Defoliation injury by bean leaf beetle adults is generally not serious in Ontario. The exception is damage caused by overwintering adults to young soybean plants (V1 to V2). Adult feeding appears as small round holes between the major leaflet veins. Pod feeding is another concern. BLB feed on the surface of the pod, leaving only a thin film of tissue to protect the seeds within the pod. These pod lesions increase the pod's susceptibility to secondary diseases such as *Alternaria*. The most important concern is that BLB vectors bean pod mottle virus. The virus causes the plant and seed to become wrinkled and mottled, reducing the quality of the seed. For more information on this disease, see the section *Bean Pod Mottle Virus*, on page 130.

Scouting Technique: During the seedling stage, select at least five sampling sites from across the entire field at random. At each sampling site, slowly walk down 4.5–6 m (15–20 ft) of row and carefully count all beetles. Do not disturb the plants, but check closely enough that you can see the underside of the leaves. Calculate the average number of beetles per foot of row.

For fields beyond the seedling stage, select at least five sampling sites from across the entire field at random. Determine the percent defoliation that has occurred, using Figure 4–5, *Defoliation Chart for Soybean Leaf-Feeding Insects*, on page 120.

Damage Thresholds: In seed fields and beans grown for Asian export, BLB should be controlled to avoid bean pod mottle virus. Thresholds for bean leaf beetle range from 16 adult beetles per foot of row in early seedling stages to over 39 per foot of row at V2+ stages. If the defoliation exceeds the thresholds in Table 4–20, *Standard Damage Thresholds for Soybean Insect Defoliation*, on page 120, then a rescue treatment may be warranted to prevent excessive yield loss.

Management Strategies: See OMAFRA Publication 812, *Field Crop Protection Guide*, for insecticide recommendations. Spraying for BLB on seedlings may be necessary in a seed or export crop. Rescue treatments for bean leaf beetles later in the season are usually not economical due to the soybean plant's tolerance to defoliation and the great number of beetles needed to reach thresholds. The field planted earliest in a local area is usually the most attractive. Consider planting export or seed soybeans a few days later than crushing soybeans.

Japanese Beetle

Description: The adult beetles are approximately 13 mm in length and can be easily identified by their bright, metallic-green head and coppery wings tinged with green edges (see Plate 62 on page 285). They have 12 white tufts of hair along the boundary of their wings. The larvae are white, C-shaped grubs about 2 cm in length.

Life History: Japanese beetles overwinter as larvae in the soil below the frost line. Once temperatures increase, larvae migrate closer to the soil surface, feed on plant roots and then pupate. Adults emerge from the soil late June to late July and remain active for about 30–45 days. Adults mate during this time, and the females lay their eggs in damp soil. During periods of drought, eggs may be laid in poorly drained ground, irrigated areas or fallow fields where loose soil allows for the easy deposition of eggs. Egg-laying continues until late July and August. Eggs hatch in about 2 weeks. Newly hatched grubs feed on the roots in the upper 10 cm of soil. By late September, grubs begin to migrate to below the frost line to overwinter.

Damage: Grub (larvae) damage in soybeans is usually minimal. Adult feeding causes leaves to appear skeletonized.

Scouting Technique: Scout 20 plants in at least five areas and compare the damage found to Figure 4-5, *Defoliation Chart for Soybean Leaf-Feeding Insects*, on page 120.

Economic Thresholds: If the defoliation exceeds the thresholds in Table 4-20, *Standard Damage Thresholds for Soybean Insect Defoliation*, on page 120, a rescue treatment may be warranted to prevent excessive yield loss.

Management Strategies: Chemical control is only recommended when populations and damage exceed economic thresholds. There are quarantine restrictions to the transportation of soil, manure, compost, tubers and grass sod from infested fields in several counties of Ontario and Quebec. Consult the Canadian Food Inspection Agency for further information on these restrictions.

Grasshoppers

Description: There are several species of grasshoppers that vary in colour from green to brown. Nymphs look similar to adults but are smaller and have incomplete wings. Both stages feed by chewing. All species have enlarged hind legs for jumping.

Life History: Grasshoppers overwinter as eggs in the soil, usually in uncultivated fields and pastures. Nymphs hatch from the eggs in early June and begin feeding on emerging plants. Nymphal stages last for approximately 2 months with adults appearing later in the season to feed, mate and oviposit their eggs in the soil for next year's population. Grasshoppers prefer to lay eggs in sandy soils with grassy, undisturbed areas. Drought conditions for 1-2 years favour egg and nymph survival.

Damage: Both adults and nymphs feed on the leaves, pods and seeds. High infestations can defoliate fields, causing yield loss. Feeding damage usually begins around the borders of fields, adjacent to grassy fencerows. High-risk factors include no-till, grassy fields, dry autumns and mild winters.

Scouting Technique: Begin scouting in late June when grasshoppers are still young. Scout adjacent fencerows and grassy borders. Later in the season, begin scouting border rows in fields to determine the stage of the soybeans and the level of defoliation and pod feeding.

Action Thresholds: If the defoliation exceeds the thresholds shown in Table 4-20, *Standard Damage Thresholds for Soybean Insect Defoliation*, on page 120, a rescue treatment may be warranted to prevent excessive yield loss.

Management Strategies: Early-season control should be concentrated on the boundaries of the field in those areas with high nymphal populations. Refer to OMAFRA Publication 812, *Field Crop Protection Guide*, for insecticide recommendations. Several natural enemies, including ground beetles and crickets, feed on the egg stage while birds and spiders feed on the nymph and adult stage, helping to reduce the populations. A fungus *Entomophthora grylli* can reduce the populations when weather conditions are warm and humid. Removal of grassy weeds in fields and borders by tillage helps reduce nymphal numbers that require these plants to survive. Tillage buries eggs deeper in the soil, hindering nymphal emergence. Chemical control is more effective on nymphal stages than adults.

Diseases

Seed Rots and Seedling Blights

Seed rots and seedling blights are caused by a number of different fungi. In Ontario, five fungi are most often associated with early-season emergence problems in soybeans. These include *Pythium* and *Phytophthora* (called "water moulds"), *Phomopsis*, *Fusarium* and *Rhizoctonia*. Typical "damping-off" symptoms can be caused by one or more of these organisms.

Appearance: It is difficult to distinguish between these pathogens since they seldom produce distinctive symptoms. Seed infected by these organisms can rot in the ground or die shortly after germination. This phase is referred to as "preemergent damping-off," since the seed fails to emerge from the ground, resulting in "gaps" or stand problems. Seedlings that do emerge can be diseased as well. "Postemergent damping-off" symptoms include delayed growth, wilting, dieback and/or death. In most cases, infected seedlings will have a "pinching" or "girdling" of the stem near the soil line. Lesions that appear water-soaked with brown or purple roots or lower stems are often the result of infection by *Pythium*, *Phomopsis* or *Phytophthora*. A reddish or brown lesion near the soil line is characteristic of *Rhizoctonia* or *Fusarium* (see Plate 63 on page 285), respectively. Growth and vigour are often reduced in those plants that do survive.

Disease Cycle: Although these organisms can be seedborne, they are present in most fields to some degree. Seedling diseases are prevalent under cool wet conditions that keep the soil temperatures below 13°C (55°F). These organisms often survive as saprophytes, living on dead plant material, or as dormant mycelium or spores. Root exudates from germinating seedlings or growing roots stimulate the inactive fungi.

Management Strategies: Low-lying or poorly drained areas of the field are often the first to show disease problems. Increased drainage through tiling will remove excess moisture, increase soil warming in the spring and help maintain a well-drained seedbed. These diseases can be more severe in no-till or reduced tillage fields. Heavy residues keep soil temperatures cooler and wetter longer than conventional fields. Timely planting into good soil conditions will help minimize losses to early season dieback, regardless of the tillage system. When dealing with these diseases, rapid emergence and good early-season vigour are important. Other factors that delay germination and emergence include environmental conditions, compaction, crusting and deep planting. Fungicidal seed treatments increase germination and emergence and therefore are recommended. Delayed germination will also affect the performance of a fungicidal seed treatment. The average fungicide seed treatment provides up to 2 weeks of protection. There is no replacement for timely planting into a good seedbed. For seed treatment recommendations, refer to OMAFRA Publication 812, *Field Crop Protection Guide*.

Phytophthora Root Rot

Incidence: Phytophthora root rot is a potential problem in heavy clay soils in Southwestern Ontario. It remains one of the most destructive diseases of soybeans in Ontario. Losses to Phytophthora root rot have occurred in the province since the 60s. The disease has also been observed in Central and Eastern Ontario. As soybean production continues to expand in those areas, so will this disease.

Appearance: The disease can affect soybeans at any stage of development but is often most damaging when it occurs early in the season. Plants infected at the primary leaf stage display typical "damping-off" disease symptoms. Seeds may fail to emerge, or infected seedlings are killed shortly after emergence. Infected areas of the stem are water-soaked or "bruised" and disintegrate easily (soft rot) (see Plate 64 on page 285). Since it causes a "wet rot," it is difficult to distinguish Phytophthora root rot from Pythium root rot at this stage. Both diseases cause taproot and lateral root pruning or rotting resulting in yellowing of the leaves, wilting and even death. Infected plants are easily pulled from the ground since the plants are not well anchored. Older plants can be affected any time before maturity. A purple or dark-brown discolouration of the stem may extend from the roots (just below the soil line) to the lower nodes of wilted plants. Dead plants may appear a few in a row or as patches in low areas of fields. Leaves will often remain attached to the plant even after death.

Disease Cycle: Cool, wet weather favours disease development. Low areas, poorly drained and slow-drying areas of the field are most prone to the disease. Heavy clay soils, reduced tillage and monoculture of soybeans may increase the damage due to the disease. *Phytophthora* and *Pythium* are unique organisms, in that they produce mobile spores that can swim in the water film between soil particles to locate soybean roots. The fungus colonizes the root tissue and will plug the water-conducting tissues of the plant, resulting in wilting of the plant. See the section *Diseases*, on page 122, for more information concerning the uniqueness of *Phytophthora*.

Management Strategies: Control of Phytophthora root rot requires a combination of soybean variety selection, seed treatment and good soil management. Soybean varieties with resistance or tolerance to Phytophthora root rot are available. Some varieties have both resistance and tolerance. **Select soybean varieties that have both specific resistance (Rps genes such as 1K and 1C) and good partial resistance (tolerance) to all races of *Phytophthora*. Varieties containing only the Rps 1a source of *Phytophthora* resistance may not be very effective in many parts of the province. Many *Phytophthora* races have developed over the years that can bypass the Rps 1a resistance. Consult with your seed company for variety profiles, especially with new varieties or technologies such as herbicide**

resistance. Consult the current report, *Ontario Soybean Variety Trials,* available on the Ontario Soybean Growers Web site at www.soybeans.on.ca for plant loss ratings for Phytophthora root rot and resistance genes in varieties.

1. **Resistant varieties.** The *Phytophthora* fungus is present in Ontario soils as a series of races (or "strains"). Resistance in any one soybean variety is effective against some but not all of the races. Root rot is controlled in a particular field when the variety grown is resistant to all of the *Phytophthora* races that happen to be present in that field. Resistance will "break down," however, should another race appear to which the variety is not resistant. If this occurs, switch to a variety that is resistant to the new race or use a tolerant variety or a different gene for resistance. Varieties with different resistance genes should be grown in rotation. To determine which races may be present in a field, plant strips of several varieties with known race resistance.

2. **Tolerant varieties.** Some disease develops in these varieties when grown in infested soils, regardless of which races of *Phytophthora* are present. However, yields of tolerant varieties usually are not seriously reduced by the disease.

Any soil management practice that reduces soil compaction or waterlogging will decrease the incidence of Phytophthora root rot. On clay soils where the disease may be a problem, the following procedures are recommended:

- Choose a variety with a low percentage of infected plants. (See the *Ontario Soybean Variety Report.*)
- Rotate with corn and wheat. A short rotation will result in a higher population and an increase in the number of races present in the field.
- Do not work the field when the soil is wet.
- Use good soil management practices to improve soil structure and drainage (rotation, manure, cover crops, reduced tillage, etc.)
- Tile inherently slow-draining fields.
- A small amount of tillage will help warm soil and increase surface drainage.
- Plant when soil temperatures are above 13°C (55°F).
- Refer to OMAFRA Publication 812, *Field Crop Protection Guide,* for recommended seed treatments.
- Inspect each soybean field for dead plants in late July or early August to determine whether the variety has enough resistance/tolerance to provide adequate protection under local conditions.

Rhizoctonia Root Rot

Incidence: Rhizoctonia root rot has been found in most of the soybean-growing areas of the province. In most fields, stand losses range from less than 5% to over 50% in severe cases. The disease has been increasing in importance and can result in substantial yield losses. It is most prevalent on seedlings and young plants, causing a root and stem rot, particularly during prolonged wet periods.

Appearance: Rhizoctonia root rot causes preemergence (seed rot) and postemergence (seedling blight) damping-off on affected seedlings. A characteristic reddish lesion is produced on the stem at or just below the soil line (see Plate 65 on page 285). These firm, dry, brick-red lesions can join, forming a sunken girdling of the stem that may move down the taproot, pruning roots along the way. Symptoms of the disease are very similar to plants infected with Phytophthora root rot. Affected plants are pale yellow, which is often confused with nitrogen deficiency symptoms or poor nodulation. Severely infected plants may lose their leaves. Wilted and/or dead plants often occur in small patches. Stem lesions girdle the stem and weaken the plant, often causing infected plants to break at the soil line under stormy conditions. Stressful growing conditions favour this disease. Rhizoctonia root rot is most damaging when cool, wet conditions in the spring are followed by hot, dry conditions.

Disease Cycle: This disease affects a large number of field and horticultural crops. It occurs on all soil types and environmental conditions. Disease losses are greatest when a wet spring is followed by dry conditions. The fungus is primarily a soil inhabitant and survives as resting mycelium or sclerotia. Under optimum temperature conditions (25°C–29°C or 77°C–84°F), disease severity will be greatest in fields that have a history of the disease. Over time, smaller infected areas increase in size.

Management Strategies: Few management options exist since no resistant and few tolerant varieties are presently available. Crop rotation with corn and small grains can help minimize the disease. Maintain good soil drainage and avoid planting under cool, wet conditions. Fungicide seed treatments offer some measure of protection and increase emergence. Further information on fungicide seed treatments can be found in OMAFRA Publication 812, *Field Crop Protection Guide.*

Phomopsis Seed Mould, Pod and Stem Blight

Incidence: Traditionally, Phomopsis seed mould has been Ontario's most important soybean seed disease. It is most problematic when the weather conditions at harvest are warm and wet. Delaying harvest under these conditions will increase the incidence of this disease.

Appearance: There are two *Phomopsis* diseases that occur in Ontario: Phomopsis seed mould and Phomopsis pod and stem blight. Phomopsis seed mould is characterized by fine cracks that usually develop near the hilum of the infected seed (see Plate 66 on page 286). A white or grey mould may be visible on the seed surface. The yield, grade, viability and vigour of the seed can be reduced. Yield losses occur because severely infected seeds remain small and light and may be lost during harvest and cleaning operations. The second phase of the disease is referred to as "pod and stem blight." Although plants are infected early in the season, symptoms do not become apparent until after mid-season. Symptoms on the stems appear as small, black, raised dots or bumps (pycnidia) (see Plate 67 on page 286). These bumps are arranged in rows or islands on the stem. On the pods, there are also numerous black dots but they are not arranged in any particular pattern.

Disease Cycle: The fungus overwinters in seed and crop debris. Spores of the fungus are splashed on to developing plants early in the season. Warm, wet, humid weather during pod fill favours disease development.

Management Strategies: Whenever possible, grow full-season varieties that mature during the cool weather late in the growing season. Varieties that are short-season for an area tend to mature earlier when conditions are warmer and more favourable for seed mould. Pod and stem blight can be controlled or reduced by integrating one or more of the following: disease-free seed, planting later, crop rotation, plowing under soybean debris and well-timed harvest. Harvest soybeans destined for export or seed first. Seed treatment usually increases germination and emergence of seed. However, distorted seed with visible fungal growth often fails to germinate, even when treated. For information on registered seed treatments, refer to OMAFRA Publication 812, *Field Crop Protection Guide.*

Powdery Mildew and Downy Mildew

Incidence: Both of these diseases occur in all regions of the province. They are most noticeable when conditions are wet or humid. Although powdery mildew and downy mildew occur in most fields, they are considered minor diseases and economically insignificant.

Appearance: Powdery mildew appears as a white powdery growth of the mildew fungus on the upper surface of the leaf (see Plate 68 on page 286). The seeds do not become infected. Downy mildew appears as yellow-to-brown spots on the leaves during late July through September (see Plate 69 on page 286). In moist weather, a pale blue-to-grey, downy growth of the mildew fungus appears on the lower leaf surface, directly under these spots. Severely affected leaves may drop prematurely. Whitish growth of the fungus may encrust the seeds, affecting even healthy pods. Planting infected seed may result in diseased seedlings.

Disease Cycle: Powdery mildew develops on the leaves, usually in August and September. Outbreaks arise when disease symptoms begin in early July and the environmental conditions remain cool, cloudy and humid through to pod fill. Downy mildew survives in infected leaves and on seed. Air-borne spores blown into Ontario from the U.S. are the most common cause of infection.

Management Strategies: Removal of crop residue and rotation with non-host crops such as corn and wheat will help prevent both diseases. Fungicidal seed treatments will reduce seed-borne downy mildew. Refer to OMAFRA Publication 812, *Field Crop Protection Guide,* for recommended products.

White Mould (Sclerotinia)

Incidence: White mould is a sporadic disease that occurs to some degree in Ontario. The disease is most damaging when cool, wet conditions occur during flowering or near harvest.

Appearance: Stems and pods infected with white mould are pale brown and water-soaked in appearance (see Plate 70 on page 286). Frequently, a white, cotton-like growth and small black bodies (sclerotia) can be seen on or within stems of diseased plants (see

Plate 71 on page 287). Plants are generally killed in patches late in the growing season. Pods infected with white mould can result in seed infection. Infected seed has a loose, white, fungal growth on the seed. **Do not use seed from infected fields.**

Management Strategies: In fields with a history of white mould, avoid growing other host crops such as canola, edible beans, buckwheat and sunflowers for 3–4 years. Planting no-till wheat after soybeans will cause the new sclerotia to remain on the soil surface. Only those sclerotia found in the top 2.5 cm of the soil will germinate. If no tillage is carried through the following crops, most of the sclerotia left on the surface will have been expended. Deeply buried sclerotia are unlikely to cause a problem for future bean crops, unless they are brought to the surface through tillage.

Some differences in susceptibility to this disease have been noted between varieties. No resistant varieties have been identified, but field observations indicate that early varieties in a geographic area are less prone to an epidemic than later varieties. Similarly, varieties with greater lodging resistance tend to be more resistant to white mould. For soybean fields with a history of severe white mould infection, producers should consider planting varieties that require 200–300 fewer crop heat units than available for the area and that possess superior resistance to lodging.

Soybean Cyst Nematode

Incidence: Since it was first identified in 1988, soybean cyst nematode (SCN) has been identified in nine counties in Ontario. Infected counties include Essex, Kent, Lambton, Elgin, Perth, Haldimand-Norfolk, Middlesex, Huron and Oxford. Unfortunately, soybean cyst nematode will continue to move across the province into previously non-infested counties. The disease can be managed effectively, but the first step is identification and awareness. All soybean producers should be scouting and testing for SCN. Losses to SCN in Ontario have ranged from 5% to 100%. Unfortunately, by the time SCN symptoms become visible on the plants, the producer has lost 25% to 30% of the yield potential. Once a field has SCN, eradication is impossible.

Appearance: These microscopic, worm-like nematodes damage the root system and prevent the uptake of water and nutrients. Typical SCN symptoms include yellowing of the leaves and stunting of plants, particularly on lighter soils under dry conditions (see Plate 72 on page 287). Damage occurs in a circular pattern ranging from a few metres to over 50 m in diameter. SCN damage is often confused or misdiagnosed as nutrient deficiency, flooding, herbicide injury, compaction or root rot damage. Yellowing of the leaf margins can resemble potassium deficiency symptoms, however, the addition of potassium will not reduce the damage from SCN or eliminate symptoms. Poor stand establishment can be the result of SCN infection and is often confused with seedling diseases. Never try to pull up a plant to see SCN. Too much root will be lost and the nematodes will be stripped off as the roots are pulled through the soil. Instead, use a shovel and dig up the plant along with the soil surrounding the roots.

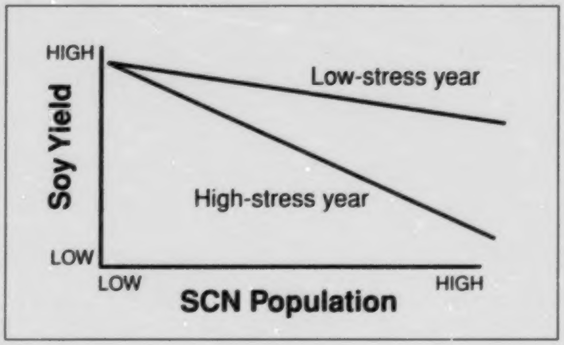


FIGURE 4–6.
Soybean Yield Response to High and Low SCN Populations Under High and Low Stress Conditions

Roots of infected plants may be dark due to secondary root rot infection and have fewer nodules. White to yellow-brown cysts less than 1 mm in diameter (pinhead) are also visible on the roots (see Plate 73 on page 287). Nematode injury symptoms (including plant death) are most obvious under stressful growing conditions, especially under hot, dry circumstances. Under good growing conditions with little stress, the visual damage from soybean cyst nematode may go unnoticed. This is in contrast to what happens in high-stress years. Under high-stress conditions, lower SCN numbers cause considerably more visual damage and hence the corresponding yield loss. A soybean plant's ability to compensate for the SCN feeding injury is less likely under high-stress conditions than when good growing conditions exist (see Figure 4–6, *Soybean Yield Response to High and Low SCN Populations Under High and Low Stress Conditions*, above).

SCN infection symptoms may not be obvious and yield reductions of 25% to 30% on susceptible fields

Table 4–21.
Hosts for Soybean Cyst Nematode

Hosts High Reproduction	Non Hosts or Hosts With Limited Reproduction
Soybeans	corn
Dry beans	wheat
Kidney beans	oats
Mung beans	clover
Adzuki beans	alfalfa
Green beans	birdsfoot trefoil

can occur without visual (above-ground) symptoms. Areas of the field where above-ground SCN symptoms will most often occur include entrance points for equipment into the field, equipment and vehicle storage areas, tops of knolls, compacted headlands, and along the fencerow where wind-blown soil tends to accumulate.

Disease Cycle: The life cycle of SCN has three major stages: egg, juvenile and adult. The cycle begins when eggs hatch to release worm-shaped juveniles in the soil. This is the only stage when SCN can infect soybean roots. Soybean plants release chemicals that attract the larvae to the roots. Once they have penetrated the roots, the young nematodes migrate to the water and nutrient-conducting tissue (vascular system) and establish a feeding site (syncytia). Syncytia form when female juvenile nematodes inject secretions into the root cells, modifying and transforming them into specialized feeding cells. At this stage, the female nematode begins to swell and eventually breaks through the root surface. Adult females that remain attached to the root to feed, produce eggs in a mass or egg sac outside of the body. As the life cycle nears completion, eggs also develop within the female's body cavity. These egg-filled bodies of the adult females are called "cysts." Initially white, the cysts turn yellow and brown as females mature. Each cyst can contain 100 to 300 eggs. The number of cysts per plant varies from a few to many hundreds. In infected soil, cysts are distributed throughout the root zone.

Management Strategies: The following practices will decrease the likelihood of this pest causing significant economic losses:

1. Plant certified or good-quality, clean seed that is free of soil peds.
2. Wash soil off farm equipment when moving it between infested fields or farms.

Table 4–22.
Potential Risk of Yield Loss for Various SCN Population Levels

SCN population (eggs per 100 gm of soil)	Risk Rating	Potential Yield Loss	Rotation
0–500 (coarse, sandy soils)	Low risk	0%–20%	4 year
0–1,000 (fine-textured silt or clay)	Low risk	0%–20%	4 year
1,000 (coarse, sandy soils)	High risk	20%–50%	6 year
2,000 (fine-textured silt or clay)	High risk	20%–50%	6 year
10,000 (all soil types)	Resistant variety may be damaged	50%–100%	non-host

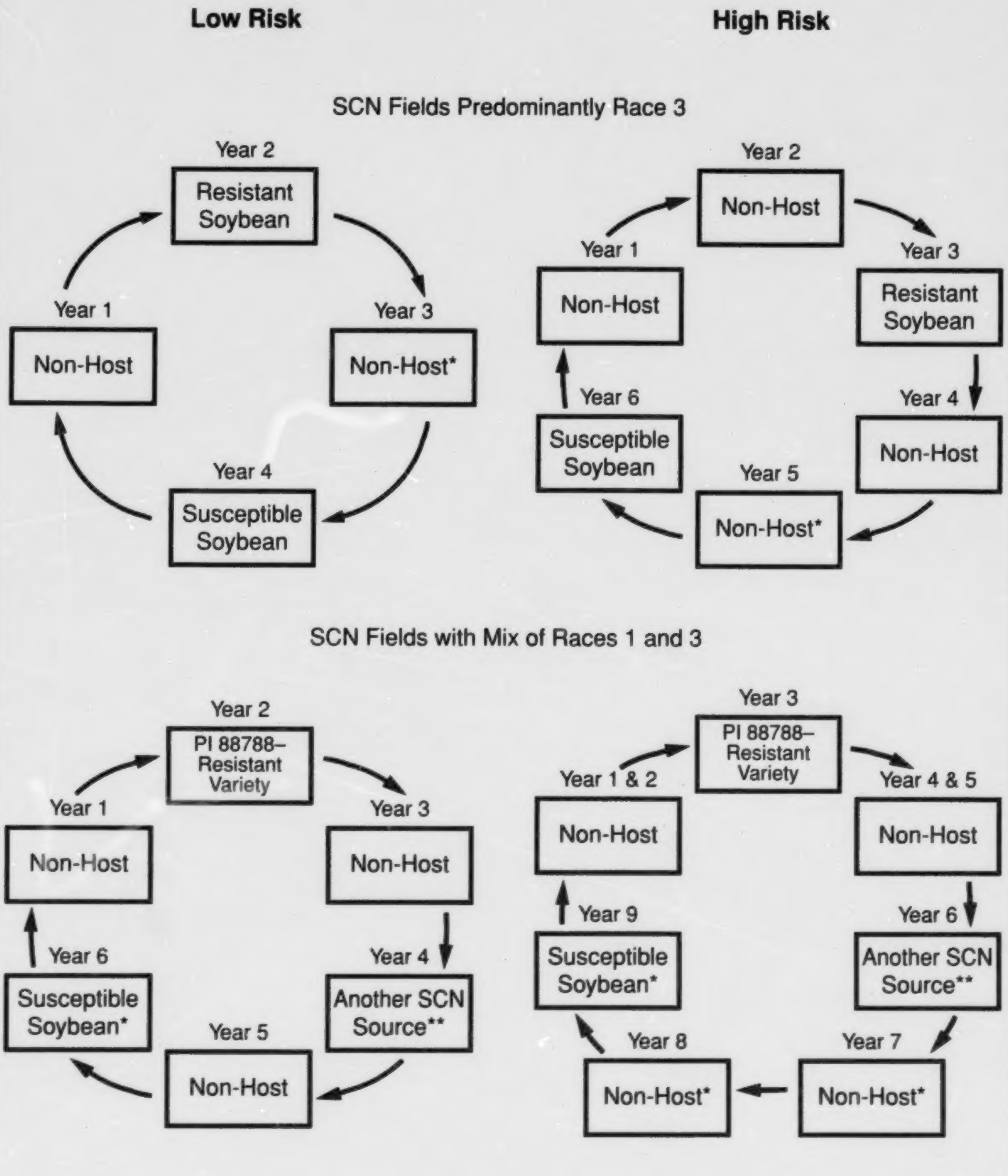
Source: Welacky, Anderson and Tenuta. Agriculture and Agri-Food Canada and OMAFRA, 2000.

3. Use proper soil conservation practices to reduce soil movement between fields.
4. Practice prudent weed control. Many weeds may serve as hosts to SCN.

If SCN has been diagnosed in a field, establish a rotation that uses SCN-resistant soybean varieties and non-host crops such as corn, wheat, alfalfa, clover or vegetable crops like tomatoes. This will lower SCN populations and improve yields on SCN-infested fields. It is not advisable to substitute edible (white, coloured) beans or peas into the rotation instead of soybeans since these other crops are also hosts for soybean cyst nematode. Refer to Table 4–21, *Hosts for Soybean Cyst Nematode*, left, Table 4–22, *Potential Risk of Yield Loss for Various SCN Population Levels*, above, and Figure 4–7, *Crop Rotations for SCN Management for Fields with Race 3 or a Combination of Races 1 and 3*, on page 128.

Monitoring of the soybean cyst nematode population in the soil is necessary. These samples should be taken every 2–3 years. Producers should ask for both an egg count and a total cyst count. Send samples for nematode analysis to any of the laboratories listed in Appendix G, *Soybean Cyst Nematode–Testing Laboratories*, on page 262.

Continuous use of resistant varieties will pressure the nematode population to adapt and shift in the field thereby making the variety ineffective in combating this pest. Consult the *Ontario Soybean Variety Trials* report for SCN-resistant varieties and their performance on infested soil.


Low Risk
High Risk
SCN Fields Predominantly Race 3
Year 2
Resistant Soybean
Year 1
Non-Host
Year 3
Non-Host*
Year 4
Susceptible Soybean
Year 2
Non-Host
Year 1
Non-Host
Year 3
Resistant Soybean
Year 6
Susceptible Soybean
Year 4
Non-Host
Year 5
Non-Host*
SCN Fields with Mix of Races 1 and 3
Year 2
PI 88788–Resistant Variety
Year 1
Non-Host
Year 3
Non-Host
Year 6
Susceptible Soybean*
Year 4
Another SCN Source**
Year 5
Non-Host
Year 3
PI 88788–Resistant Variety
Year 1 & 2
Non-Host
Year 4 & 5
Non-Host
Year 9
Susceptible Soybean*
Year 6
Another SCN Source**
Year 8
Non-Host*
Year 7
Non-Host*

*Soil sample prior to using a susceptible soybean variety (both rotation system)
**Peking or different SCN-resistant variety

Figure 4–7.
Crop Rotations for SCN Management for Fields with Race 3 or a Combination of Races 1 and 3

Caution: SCN will significantly reduce yields, therefore when selecting soybean varieties for fields with a history of SCN, make sure that the variety has SCN resistance. This is especially true for new technologies or traits such as herbicide resistance. For example, when using a herbicide-resistant variety, minimize SCN losses by selecting a variety that also has SCN resistance.

Table 4–23.
Symptom Expression on Roots, Stems and Leaves for Brown Stem Rot, Stem Canker and Sudden Death Syndrome on Soybeans

Plant Part	Brown Stem Rot	Stem Canker	Sudden Death Syndrome
Roots	• healthy	• healthy	• root rot • browning of roots • internal browning of tap root
Exterior stem	• healthy	• dark, reddish-brown sunken canker starting at node • canker may extend length of stem • often on one side	• healthy
Interior stem	• brown pith (centre) • white tissue below stem surface	• begins with slight browning at nodes • severely diseased stems completely deteriorated	• white, healthy pith • browning of tissue below stem surface
Leaves	• wilting of upper leaves • yellow spots between veins • increase in size until all tissue between veins is yellow, then brown • leaves remain attached to plant	• general yellowing of leaves • no distinct yellow spots or blotches • interveinal yellowing can lead to necrosis or dead tissue	• wilting of upper leaves • yellow spots between veins • increase in size until all tissue between veins is yellow, then brown • leaves remain attached to plant

Brown Stem Rot (BSR), Stem Canker and Sudden Death Syndrome

Incidence: All three diseases are found in all soybean-growing areas of Ontario but are more common in southwestern counties. All of these diseases are increasing, most likely as a result of changes in tillage practices. Yield losses range from a few bushels to significant portions of the field being killed (especially for sudden death syndrome).

Appearance: To aid in correctly identifying these diseases, refer to Table 4–23, *Symptom Expression on Roots, Stems and Leaves for Brown Stem Rot, Stem Canker and Sudden Death Syndrome on Soybeans,* above.

Brown Stem Rot (BSR): Symptoms of the disease generally develop in August during pod fill. Upper leaves develop yellow and necrotic areas between the veins similar to sudden death syndrome. Plants wilt suddenly, and pods are poorly filled. The disease is more prevalent with minimum tillage.

Stem Canker: This disease may cause seedling damping off and wilt but commonly affects soybean plants after flowering. Plants wilt suddenly, and leaves and petioles droop, resembling symptoms of Phytophthora root rot. Brownish-red lesions appear on the exterior of diseased plants at lower nodes (see Plate 75 on page 287). The pith of diseased plants is generally brown near the nodes. The fungus can also cause a stem or tip dieback late in the growing season. The fungus can cause seed mould similar to Phomopsis seed mould. Stem canker overwinters in crop debris and is more prevalent in minimum tillage situations.

Sudden Death Syndrome (SDS): Infected plants wilt and die very quickly in July and August. Interveinal chlorosis and necrosis of the upper leaves (see Plate 74 on page 287) and defoliation may occur. Petioles are generally retained. Wet soils and warm temperatures are conducive to disease development. A slight brownish discolouration occurs in crowns of affected plants. The disease is frequently but not always associated with soybean cyst nematode.

Disease Cycle: All of these fungi survive long periods in crop debris (residue) in the soil. Brown stem rot infects early in the growing season but does not appear until a month before harvest. Conditions during pod fill affect disease development. Development is favoured when conditions during pod-fill are cool and wet followed by hot and dry. Stem canker prefers moderately warm, wet weather and occurs from mid-July to maturity. Plants infected with sudden death syndrome begin showing symptoms from flowering to maturity and prefer cool, moist soil conditions. Well-fertilized or vigorously growing fields are most likely to show the sudden death syndrome symptoms.

Management Strategies: Crop rotation with corn and small grains will reduce the incidence of disease. These diseases occur most often on reduced tillage fields. Incorporation or removal of infested residue will reduce the risk of these diseases. A few resistant or tolerant varieties are available. Check with your seed company for variety profiles.

Soybean Mosaic Virus

Incidence: Low levels of this disease occur in most areas of the province. Food grade or specialty beans requiring blemish-free seed coats are at the highest risk of economic losses due to the soybean mosaic virus.

Appearance: Leaves of infected plants are distorted, wrinkled and puckered and have a typical mosaic pattern that is most evident on younger leaves (see Plate 76 on page 287). Infected plants may be stunted. Infected seeds have a characteristic brown or black discolouration extending in streaks from the hilum region (see Plate 77 on page 288). Virus symptoms are often confused with hormonal herbicide injury. Plants infected with soybean mosaic virus are scattered in the field, and generally the area affected is smaller than if the cause were herbicide injury. In addition, there is no pattern to the injury.

Disease Cycle: The virus survives from season to season in infected seed and is transmitted from plant to plant by aphids.

Management Strategies: Planting disease-free seed controls the disease in Ontario.

Bean Pod Mottle Virus

Incidence: Bean pod mottle virus has caused significant economic losses in the midwestern United States and has recently been identified in Ontario. Bean pod mottle virus can affect soybean quality and therefore, export potential.

Appearance: A common symptom of virus infection is uneven crop maturity or "green stem" in which stems and leaves remain green even though pods have matured. Young leaves in the upper canopy often have a green-to-yellow mottling that may fade and then redevelop later in the growing season. In severe cases, malformed leaves and pods may be produced. Infected leaves show reduced turgidity resulting in curling. A reduction in the number of pods often occurs in infected plants that have undergone dry or drought stress. Infected seed coats are mottled with brown or black streaks extending from the hilum.

Disease Cycle: Cool weather enhances disease development. Unlike soybean mosaic virus, bean pod mottle virus does not spread very efficiently in seed but is primarily vectored by the bean leaf beetle and possibly the cucumber beetle. The virus has a wide host range among legumes and will be transferred to bean leaf beetles that feed on infected legume plants. The virus can be spread by mechanical injury, especially under wet conditions.

Management Strategies: Plant disease-free seed or resistant varieties in areas with a history of the disease. Consider controlling bean leaf beetle adults when populations are high early in the season. For bean leaf beetle thresholds, see the section *Bean Leaf Beetle (BLB)*, on page 121.

Other Crop Problems

Frost and Hail Damage

Early Season

Plants damaged below the cotyledons by early-season frost or hail will not recover. If frost or hail damages the growing point of the seedling, but not the stem portion below, the plant will send out new shoots from the base of the leaves or cotyledons (see Plate 78 on page 288). Wait 3 or 4 days and watch for new growth to emerge from the point where leaves attach to the stem (leaf axils). Research trials show that leaf loss at early growth stages has little impact on final yield or maturity. Table 4-24, *Percent Yield Loss of Indeterminate Soybean at Various Levels of Leaf Area Loss and Growth Stages*, on page 131, summarizes the expected yield loss from leaf loss at various life stages.

Stem Damage

Broken or cut-off stems have greater impact than leaf loss on yield and maturity. If stem loss is under 50% prior to flowering, yield loss will be less than 10%. When evaluating hail damage, check for bruising on the plant stem. Severe damage to the stem will make it more difficult for the plant to recover (see Plate 79 on page 288). It can also make the plant more susceptible to disease. Bruising, which does not cause stem breakage, causes minimal loss in yield.

In terms of yield reduction, soybeans are most vulnerable during the flowering and seed fill period. This is particularly true if stems are broken, resulting in a reduction in the number of pods. Delays in maturity and seed size also occur.

Table 4–24.
Percent Yield Loss of Indeterminate Soybean at Various Levels of Leaf Area Loss and Growth Stages

	Percent Leaf Area Destroyed									
Growth Stage	10	20	30	40	50	60	70	80	90	100
Vc-Vn	–	–	–	–	–	–	–	–	–	–
R1	–	1	2	3	3	4	5	6	8	12
R2	–	2	3	5	6	7	9	12	16	23
R2.5	1	2	3	5	7	9	11	15	20	28
R3	2	3	4	6	8	11	14	18	24	33
R3.5	3	4	5	7	10	13	18	24	31	45
R4	3	5	7	9	12	16	22	30	39	56
R4.5	4	6	9	11	15	20	27	37	49	65
R5	4	7	10	13	17	23	31	43	58	75
R5.5	4	7	10	13	17	23	31	43	58	75
R6	1	6	9	11	14	18	23	31	41	53
R6.5	4	7	10	13	17	23	31	43	58	75

Source: National Crop Insurance Services Inc., 1997.

Late Season Cold Temperature and Frost Injury

Soybeans are regarded as a warm-season crop and are therefore more susceptible to cold temperatures, especially during flowering. It is believed that sustained cold temperatures (less than 13°C or 55°F) during flowering affect proper formation of pollen in the flower. This results in poorly developed pods called parthencarpic pods (also called "monkey pods"). There is some variety difference in tolerance to cold temperatures as was experienced in 1992.

Varieties that have tawny pubescence (i.e., yellowish-brown hair) are more cold tolerant than those that have grey pubescence.

Frost during flowering and pod fill can drastically reduce yield and quality (see Table 4–25, *Soybean Response to Freeze Damage*, above). Freezing during pod fill will result in severely damaged beans with a greenish, "candied" appearance.. Even moderately frosted beans with a greenish colour and slightly wrinkled seed coat are considered damaged and can be discounted if present in excess of limits. The seed will eventually dry down with a wrinkled seed coat. Frost-injured plants may reach maturity earlier but will have seed moisture equal to non-frosted plants. Germination will also be severely reduced. The Canadian Food Inspection Agency classifies frost-damaged soybeans as those "soybeans whose cotyledons, when cut, are green or greenish-brown in colour with a glassy, wax-like appearance."

Table 4–25.
Soybean Response to Freeze Damage

Growth Stage		Yield Reduction
R4	Full pod	70%–80%
R5	Beginning seed	50%–70%
R6	Full seed	15%–30%
R7	Beginning maturity	0%–5%
R8	Full maturity	0%

Source: Saliba et. al. Kansas State University, 1982.

Herbicide Injury

All herbicides have the potential to cause crop injury. Some soil-applied (preplant or premergent) herbicides can be splashed up on the leaves to cause injury, or the herbicide can be taken up through the roots. With postemergent herbicide products, most injuries occur at the time of application or shortly after. Spray from the target crop can also cause injuries to a neighbouring, non-target crop susceptible to the herbicide applied. Spray overlaps are also common places to find crop injury from herbicides.

Stage of growth, crop stress, weather conditions, variety, tank-mix partners and adjuvants will all affect the amount and severity of crop injury. When the target crop is under stress, it is sometimes not able to metabolize the herbicide fast enough to avoid injury. The type of herbicide (mode of action) is a major factor in how herbicides affect crops. In general, while contact herbicides injury may look worse, systemic herbicides will cause longer-lasting injuries, which may be more severe. Always read the label for information on how to reduce herbicide injury.

See also the OMAFRA Factsheet, *Herbicide Mode of Action Categories*, Order No. 00-061, available through the OMAFRA Web site at www.gov.on.ca/OMAFRA/english/crops.

Specific Types of Herbicide Injury

Refer to the OMAFRA Factsheet *Herbicide Mode of Action Categories*, Order No. 00-061, or OMAFRA Publication 75, *Guide to Weed Control*, for herbicide trade names.

Triazine
(Examples are atrazine, metribuzin, simazine and other products containing these herbicides.)

OTHER CROP PROBLEMS

Plate 80 on page 288 shows triazine injury on the lower leaves of soybeans. Leaves will show interveinal chlorosis and a yellowing of leaf margins and tips followed by browning. Lower leaves are affected most. There may also be reduced root growth. Triazine injury usually results from carry-over in the soil of residues from applications of herbicides containing atrazine in previous years.

Metribuzin can injury soybeans through root uptake or more commonly by splash-up on the leaves (see Plate 81 on page 288). Root growth may be reduced. Heavy rains can splash herbicide from the soil surface on the leaf, causing injury. Fields with high soil pH or low organic matter soils will show more injuries. In some cases, older leaves may die and fall off while newer leaves are not injured. Yield effects are minimal unless the plants are killed. Some varieties are sensitive to metribuzin.

Chloroacetamide Herbicides (e.g., dimethenamid, flufenacet, s-metolachlor)

Plate 82 on page 288 illustrates chloroacetamide injury on soybeans. Symptoms are puckered leaves, and shortened midrib ("drawstring"); leaves sometimes appear to be heart-shaped.

Auxinic Herbicides

(Examples are dicamba and other products containing these herbicides or similar herbicides.)

Auxinic (hormone-type) herbicides such as dicamba can drift onto soybeans and cause leaf and stem malformations, such as leaf-cupping, twisting, parallel venation or leaf strapping (see Plate 83 on page 289). Low-level drift that occurs before flowering can cause significant visual injury symptoms but in many cases, this does not have a significant impact on yield. Injury can come from herbicide drift from adjacent fields or from contaminated spray tanks that were not properly cleaned out.

Diphenylether (PPO) Herbicides (e.g., aciflurofen, fomesafen)

PPO herbicides cause contact burning injury on the leaves, but newer leaves will not be affected (see Plate 84 on page 289). New leaves that are not fully expanded at the time of spraying may appear twisted or crinkled without having the necrotic spotting. Injury symptoms may occur within a few hours after application. The canopy greens up again as new leaves emerge.

Bentazon

Bentazon injury on soybeans is shown in Plate 85 on page 289. Leaves may show yellowing, bronzing, speckling or burn. Broxoynil is a herbicide with the same mode of action that is used in corn. Surfactants enhance the injury.

Acetolactase Synthase (ALS, Group 2)

Plate 86 on page 289 shows ALS injury — reddish veins on the underside of the soybean leaf (red-to-purple veins on the lower veins on the lower side of the leaf). Some ALS herbicides may also cause yellow leaf margin, crinkled leaves, yellowing near growing point, stunting and death of the growing point.

5. Forages

Forages are a major Ontario crop, using over one-third of Ontario's improved land. Hay and haylage are grown on 1,012,000 ha (2,500,000 ac), while there are 364,000 ha (900,000 ac) of seeded pasture and 648,000 ha (1,600,000 ac) of natural pasture. There are approximately 121,000 ha (300,000 ac) of corn silage grown in Ontario, which is 14% of the corn crop. The value of forage production is estimated to be approximately $800 million or about 10% of the agricultural production in Ontario.

Forages, by definition, are whole plants used to feed livestock. They are an important component of crop rotations on many farms, and their benefit has been demonstrated by numerous research trials and by grower experience.

Crop management is more complex with forages than with many other crops, for several reasons:

- Forage usually consists of a mixture of different species.
- Forage may be used as either stored feed or pasture.
- There is a wide range of harvest and storage systems used.
- Perennial crops require management for overwintering.

For information on corn silage production, see the section *Selecting Hybrids for Silage,* on page 56. Information on corn silage harvest and storage is discussed in the section *Haylage and Corn Silage,* on page 156. For more detailed information on pasture, refer to OMAFRA Publication 19, *Pasture Production.*

Species

Perennial Legumes

Most legumes grown for forages have taproots and broad, compound leaves (composed of a number of leaflets) that are arranged alternately on the stem. New shoots originate from the crown of the plant, and the growing point of each shoot is located at the top of the shoot. As a family, legumes produce higher quantities of protein than grasses.

If properly inoculated, legumes have the capacity to use atmospheric nitrogen, eliminating the need to apply nitrogen from commercial sources. Legumes also supply a considerable amount of nitrogen to the grass portion of the mixture.

Alfalfa

Alfalfa is the highest-yielding perennial forage crop grown in Ontario and the most frequently grown forage legume. It produces more protein per unit area than other forage legumes and can be grown alone or in combination with a grass species. For high yields and persistence, alfalfa requires well-drained soil, a pH above 6.1, adequate fertility and the proper harvest management. Well-managed alfalfa normally persists for 3 or more years. The protein and energy levels of alfalfa-based forage are determined by stage of growth at the time of cutting. Alfalfa has a critical fall harvest period that should be observed to avoid winterkill.

Birdsfoot Trefoil

Birdsfoot trefoil is a non-bloating legume best suited for permanent pasture situations. It is well adapted to steep or stony land that should not be cultivated, because birdsfoot trefoil will reseed itself. Although individual plants live for only a few years, stands of birdsfoot trefoil have remained productive for 10 or more years when allowed to go to seed. It is also adapted to soils with marginal drainage. Birdsfoot trefoil has a lower yield potential and is more difficult to dry than alfalfa, so it is recommended for hay production only in areas where alfalfa will not grow well. Because birdsfoot trefoil seedlings are slow to establish, it will usually take at least a year to get a satisfactory stand. Birdsfoot trefoil, like alfalfa, has a critical fall harvest period, beginning about 10 days earlier than alfalfa at the same location.

Red Clover

Red clover is a short-lived perennial. Yields are good the year after establishment but are often quite low the following year, especially in southern Ontario. It can be grown in fields that are too wet or acidic for alfalfa. When seeded in mixtures, red clover can suppress the establishment of other legumes. As a feed crop, red clover is most often stored as silage since it is difficult to dry, resulting in "dusty" or "mouldy" hay.

There are two general types of red clover grown in Ontario: double-cut or "medium" red clover and single-cut or "mammoth" red clover. Double-cut will flower in the seeding year, with vigorous regrowth after cutting. Single-cut is slower growing and matures about 2 weeks later than double-cut. Single-cut does not flower in the seeding year or after the first cut in succeeding years.

Use of red clover as a plowdown has become an important practice on many farms. See the section *Red Clover*, on page 23, for information on the use of red clover as a cover crop.

White Clover

White clover is used mainly in pastures. It is a short-lived perennial that can reseed itself. There are three general types of white clover: ladino, white dutch and small wild white. All three are similar in appearance but differ in size, with wild white being the smallest and ladino the largest. All have stolons, which are stems that creep on the ground, with branches that are erect or upward slanting. Roots are shallow and fibrous and develop from nodes of the creeping stolons. White clover has low tolerance to drought but is relatively tolerant to frequent grazing and has good palatability. White clover can be frost seeded or no-tilled into existing grass pastures to improve forage quality and yield.

Sweet Clover

Sweet clover is a slow-growing biennial often used to alleviate compaction. Sweet clover does not flower in the year of establishment. In the spring of the second year, it grows quickly to become a tall, coarse-stemmed plant. The presence of coumarin in sweet clover makes it less palatable to livestock.

There are two types: white-flowered and yellow-flowered. White sweet clover is deeper rooted, taller and coarser, which makes it more suitable for plowdown than for forage. The yellow-flowered is more palatable to livestock and more attractive to bees. **Mouldy sweet clover hay may contain dicoumarol, which can prevent normal blood clotting and result in the death of livestock from bleeding.**

Alsike Clover

Alsike clover is a perennial although it is often treated as a biennial. It can grow on soils that are acidic and poorly drained. Alsike produces only one cut of hay per year and is not normally a preferred forage legume. **Alsike clover can cause photosensitivity and liver damage in horses, so it should not be included in horse hay or pasture mixtures.**

Kura Clover

Kura clover is a pasture legume relatively new to Ontario. Kura clover has poor seedling vigour and is difficult to establish. However, once established, kura clover is very persistent, winter-hardy and can tolerate less-than-ideal drainage, fertility, pH and grazing management. It spreads by underground stems called rhizomes, has an extensive root system and thickens with time. Proper seedbed preparation and seeding methods are important. Kura clover must be inoculated with the correct strain of *Rhizobium* bacteria.

Perennial Grasses

Grasses have many long, slender leaves that are borne on a stem. They have very fibrous roots that help bind the soil together, thereby reducing erosion. Some grasses have rhizomes or underground stems that produce new shoots at each node. Grasses with rhizomes are capable of thickening up a stand. Grasses without rhizomes are known as bunch grasses.

Grass species differ in their competitiveness with legumes. This will influence the grass-legume ratio of an established stand. Grasses such as orchardgrass and the ryegrasses tend to be more competitive with alfalfa than timothy or bromegrass. Grasses are lower in protein than legumes when cut at a similar stage of development.

Timothy

Timothy is the most widely sown forage grass in Ontario and is commonly grown in mixtures with alfalfa or birdsfoot trefoil. It is a bunchgrass with limited tillering ability, which makes it non-aggressive when sown with other species. It is easy to establish in early spring or late summer and is adapted to heavier soils and variable drainage. Timothy is palatable and high yielding in first cut. Regrowth after first cut and mid-season production is not as high as that from either bromegrass or orchardgrass.

Smooth Bromegrass

Smooth bromegrass is an earlier, more aggressive grass than timothy. Better drought tolerance results in more regrowth in second cut. It spreads by rhizomes, and the stand can thicken over time. Smooth bromegrass is palatable and tends to retain its nutritional value with increasing maturity better than most grasses. Its major drawback tends to be its large fluffy seed, which makes it difficult to seed through the small seed box of drills. It does not establish well if it is either surface seeded or seeded deeper than 5 cm.

Meadow Bromegrass

Meadow bromegrass is useful as a pasture species because of its early spring growth and faster recovery rates after grazing. It is best used in rotational grazing.

Orchardgrass

Orchardgrass develops earlier and is much more aggressive than either timothy or bromegrass. It is palatable when young but loses palatability and digestibility more quickly than other grasses. Orchardgrass will grow much more vigorously in the warm, dry conditions of midsummer than timothy or bromegrass, resulting in a greater proportion of grass in the second and third cutting of alfalfa-grass mixtures. Orchardgrass is not as winterhardy as either timothy or bromegrass and will not persist on wet soils. Its aggressive seedlings make orchardgrass easy to establish. It is recommended in intensively managed pastures or as very early cut haylage.

Reed Canarygrass

Reed canarygrass has rhizomes and is best known for its ability to tolerate poorly drained soils. It can, however, provide high yields on well-drained or even droughty soils. Reed canarygrass spreads by rhizomes, develops coarse stems and leaves and quickly loses palatability and digestibility once it heads. Reed canarygrass is slow to establish and is not competitive in the year of seeding.

In the past, livestock have performed poorly on reed canarygrass because of certain alkaloids it contained. Recommended reed canarygrass varieties are free of the tryptomine and carboline alkaloids, which cause poor performance. Some varieties are lower in the gramine alkaloids that reduce palatability, intake and animal performance.

Tall Fescue

Tall fescue is a coarse, leafy grass that is useful in long-term pastures and in erosion control. It is adapted to most soil types, tolerates imperfect drainage and withstands animal traffic well. Its ability to maintain good feed quality into late fall makes it useful in "stockpile grazing." A seed-borne systemic fungus (an endophyte) has been linked to poor animal performance on tall fescue pasture. Once introduced by infected seed, the fungus cannot be controlled in an established stand of tall fescue. All recommended varieties are endophyte-free.

Meadow Foxtail

Meadow foxtail is a long-lived perennial grass that resembles timothy in appearance and is suitable for intensive pasture management. It performs well on poorly drained soils, has very early spring growth and matures very early. Midsummer production during periods of high temperature and drought may be low. Its seed is light, fluffy and hairy; coated seed should be used.

Creeping Red Fescue

Creeping red fescue is a dense, sod-forming grass that establishes and spreads vigorously on most soil types, including well-fertilized subsoils. Its solid root system and thick, fine top growth make creeping red fescue an excellent grass for streambank or grass waterway protection. It can also serve as a bottom grass in long-term pastures and is noted for its extended growth period and retained nutritional value in the fall. Its low-growing habit makes it difficult to cut and unsuitable for hay.

Meadow Fescue

Meadow fescue is a hardy grass used in hay and pasture mixtures. It grows best on deep, fertile soils but will tolerate variable drainage and low fertility. Meadow fescue yields well during the summer and fall and maintains its feed quality later into the season than most grass species. Meadow fescue is shorter and has finer leaves and a shallower root system than tall fescue and is not as persistent.

Perennial Ryegrass

Perennial ryegrass is a short-lived perennial that comes in turf-, pasture- and hay-adapted varieties. The pasture-adapted varieties tend to have finer leaves and smaller and more numerous tillers, and are later maturity than the hay varieties. Perennial ryegrass is early and vigorous in the spring, and grows well into the fall, but is unproductive during the hot, dry summer months. Winterkill is promoted by excessive top growth going into the winter. Perennial ryegrass may winterkill in alfalfa mixtures that are left to overwinter with considerable fall growth. Perennial ryegrass is not well adapted to areas with prolonged ice cover and extreme cold without adequate snow cover.

SPECIES

Bluegrass

In Ontario, two common bluegrasses, Canada and Kentucky, are grown on approximately 1 million ha of permanent pastureland. In southern Ontario, the shallow-rooted bluegrasses produce lush, palatable growth during the spring but are unproductive during the dry, hot summer. When properly fertilized and managed, bluegrass production can be markedly improved, especially in the cooler climate of northern Ontario. In pastures, they serve as a bottom grass that controls weed invasion, withstands close grazing and tramping, and fills in when other species thin out.

Table 5-1, *Characteristics of Perennial Forage Species Grown in Ontario*, on page 137, summarizes the characteristics of each perennial forage species grown in Ontario.

Annual Forages

The main annual crop that is used to provide forage is corn, which is harvested as corn silage. See the section *Selecting Hybrids for Silage*, on page 56, for more details.

There are several options for annual forage crops. They can be part of a planned cropping program or an emergency remedy to provide feed when perennial forage crops are winterkilled or in short supply. Annual forages are a valuable source of hay, pasture, silage or green feed.

Winter Cereals (Rye, Triticale, Wheat)

Fall rye, winter triticale and winter wheat can provide fall and early spring grazing. Adequate nitrogen fertility in the spring will provide good stored feed yields by late May. Feed quality decreases as the crop matures. Fall rye can be grazed in the fall if seeded between August 15 and 31. It will be ready for grazing 7 weeks after seeding. Fall rye will produce a larger volume of spring forage than winter triticale or wheat. Rye to be spring grazed should be fertilized with 50–80 kg/ha of nitrogen just before the rye turns green in the spring. Rye will begin to head out after mid-May if not grazed closely.

Winter triticale can be seeded at a similar time to fall wheat. Winter triticale seed can be difficult to source. Seed winter triticale at 100–125 kg/ha. Fertilize early in the spring with 80 kg/ha of nitrogen for spring grazing or stored feed. Winter triticale provides early spring grazing similar to fall rye.

Spring Cereals (Oats, Barley, Triticale)

Spring cereals are very adaptable for forage production. Oats and barley are used extensively as companion crops for perennial forage seedings and are usually harvested for silage. Cereals can also be used for hay or pasture.

Cereals can be seeded at any time in the season. Early spring planting promotes maximum yields and production. Nitrogen fertilizer enhances vegetative growth, and therefore 30–50 kg/ha of nitrogen are recommended. Cutting or grazing can usually begin 6–8 weeks after seeding. Forage quality drops quickly after heading, so harvest at the late boot to early heading stage to maximize feed value. Yield will increase as plants mature, but feed quality drops dramatically. Silage should be wilted to 50%–65% moisture.

Cereal silages are higher in protein than corn silage but usually lower than good-quality alfalfa haylage. Energy values are lower than corn silage and often comparable to alfalfa haylage.

Oats are preferred over barley for pasturing and hay due to their higher palatability. Mixed grain and spring wheat can also be used for forage.

For more information on spring cereal mixtures, refer to the OMAFRA Factsheet, *Forage Production From Spring Cereals and Cereal-Pea Mixtures*, Order No. 98-041, or visit the Web site at www.gov.on.ca/OMAFRA/english/crops/field/forages.

Cereal-Pea Mixtures

Field peas seeded in mixtures with cereals will enhance feed quality. Pea mixtures can increase protein levels and improve feed digestibility if the peas make up at least 50% (by weight) of the seed mixture. This will increase seed costs. Forage pea varieties are preferred. Avoid using a semi-leafless pea variety in order to maximize leaf yield. Oats with peas may be used as a companion crop for seeding alfalfa but should be harvested for silage. Cut as the oats are heading out; the peas will be just starting to pod. This growth stage will typically occur around the last week of June.

Mixtures of spring triticale and peas can be grown as a forage crop. Seeding rates and crop management are similar to that described for oats and peas. Mixtures of triticale and peas usually have more peas in the harvested forage than mixtures of oats and peas. This tends to increase quality but makes wilting slower and increases the length of time the crop must cure before ensiling.

Table 5-1.
Characteristics of Perennial Forage Species Grown in Ontario

Species	Suitability	Persistence (years)	Strengths	Cautions
Alfalfa	Stored feed	3-4 S. Ont 1-4 N. Ont	Excellent quality Excellent yield	May cause bloat Poor persistence under grazing Low tolerance to acidic or variably drained soil Needs fall rest period
Birdsfoot trefoil	Stored feed Pasture	5+ (May reseed itself)	High quality No bloat hazard Good tolerance to acidic & variably drained soil	Slow to establish Slow spring growth and regrowth Needs fall rest period Unpalatable to horses
Red clover	Stored feed Plowdown Pasture	1-3	Excellent first-year yield Easy to establish High quality Good tolerance to acidic or variably drained soil	May cause bloat Stand thins rapidly May cause temporary infertility in grazing sheep Very competitive, especially with other legumes
White clover	Pasture	5+	Excellent quality and palatability Good tolerance to close grazing	May cause bloat Low drought tolerance
Kura clover	Pasture	5+	Persistent High quality	Difficult to establish May cause bloat
Alsike	Stored feed Pasture	1-2 (may reseed)	Very good tolerance to wet, acidic soils Good quality	Lower yield than red clover Regrowth yields low Stand thins rapidly May cause bloat
Sweet clover	Plowdown Stored feed	2	Excellent soil builder Opens up subsoil Excellent bee pasture	Low palatability unless harvested early Coumarin content in older varieties causes feeding difficulties Only 1 harvest year
Timothy	Stored feed	5+	Easy to establish Good tolerance to variable drainage Seed is inexpensive	Poor summer production Poor persistence of late-heading varieties under 3-cut harvest system
Smooth bromegrass	Stored feed Pasture	5+	Excellent spring/fall yield Good regrowth Better quality retention with maturity	Large seed size may cause seeding problems
Meadow bromegrass	Pasture Stored feed	5+	Early spring growth Fast recovery after cutting or grazing Good winterhardiness Good palatability	Large seed size may cause seeding problems Sensitive to flooding Spreads less by rhizomes than smooth bromegrass
Orchardgrass	Pasture Stored feed	5	Very early pasture Excellent regrowth Good drought tolerance Good tolerance to close grazing Very responsive to nitrogen	Rapidly loses quality and palatability with maturity Very competitive with other species Poor tolerance to variable drainage and icing
Reed canarygrass	Stored feed Pasture	5+	Excellent yield on both variably drained and dry soils Good regrowth Very responsive to nitrogen	Slow to establish Rapidly loses quality and palatability with maturity Poor tolerance to close grazing or frequent cutting
Meadow fescue	Pasture	5+	Easy to establish Excellent, very early yield Excellent tolerance to variably drained soil	Coated seed required Very competitive with other species Low drought tolerance Low quality with maturity

Table 5–1.
Characteristics of Perennial Forage Species Grown in Ontario (Continued)

Species	Suitability	Persistence (years)	Strengths	Cautions
Tall fescue	Stored feed Pasture Grass Waterways	5+	High yield Good summer growth Good feed quality in fall Good tolerance to acidic soil	Coarse leaves and low palatability Need endophyte-free seed
Creeping red fescue	Pasture Grass Waterways	5+	Good feed quality in fall Easy to establish Good tolerance to close grazing and to acidic soils Good regrowth	Low seasonal yield Low palatability
Meadow fescue	Stored feed Pasture	5	Good summer yield Good feed quality in fall Fine leaves attractive to livestock	Less persistent and lower yielding than fall fescue Slow to establish
Perennial ryegrass	Pasture Stored feed	2–3 S.Ont.	Excellent quality and palatability Establishes very quickly Good tolerance to close grazing	Poor drought and heat tolerance Poor tolerance to variably drained soils Variable persistence
Kentucky bluegrass	Pasture Grass Waterways	5+	Good quality and palatability Good tolerance to close grazing	Poor summer production Very slow to establish Low seasonal yield

Forage Soybeans

Soybeans are primarily grown in Ontario for oilseed production. However, soybeans may provide a source of high-quality forage as an annual crop. Whole plant soybeans with good pod formation will have similar protein levels and digestibility to alfalfa. Soybeans can be harvested for silage but are difficult to cure for hay.

Plant height and branching ability should be taken into consideration during variety selection. Forage soybean varieties have been developed. A solid-seeded planting with a grain drill at a seeding rate of 80–100 kg/ha will provide a productive canopy for forage production. Very few herbicides are registered for use on soybeans harvested as forage. Check herbicide labels for use restrictions. An alternative would be to use a rotary hoe 7–10 days after seeding to reduce weed competition. Refer to the section *Mechanical Methods of Weed Control* in OMAFRA Publication 75, *Guide to Weed Control*. Harvest of soybean forage should take place just as the lower leaves on the plant are beginning to yellow. In Ontario, this usually coincides with the first week in September. Only one cut per season is harvested.

Warm-Season Annual Grasses

Members of the sorghum, sudangrass and millet families are semi-arid, tropical, warm-season annual grasses. Warm-season annual grasses are often considered in emergency forage situations where alfalfa has winterkilled, or when planting has been delayed. They offer advantages over corn silage in that they can be grown with conventional forage seeding and harvesting equipment. They can be used in Ontario for silage (chopped or wrapped large bale), green chop or pasture. Haying of sorghums and sudangrass is not recommended because they are difficult to cure. Millet is frequently used as haylage or possibly hay, with good drying conditions. **Sorghums and sudangrass should not be fed to horses, as they can cause cystitis, an inflammation of the bladder.** Refer to OMAFRA Publication 19, *Pasture Production*.

Millets

The name "millet" has been given to numerous grasses with small edible seeds. Most millet types, including Japanese, proso, foxtail, barnyard, Koda, finger and Teff, have short (0.3–1.2 m or 1–4 ft), slim stalks. Pearl millet is the exception to this description, with stalks over twice as long (1.5–3 m or 5–10 ft) and thicker. The millets commonly used for forage in Ontario are pearl millet and Japanese millet. With proper management, millets can produce forage with very good quality.

Millets have a smaller stem than sorghum grasses and slightly higher total digestible nutrients (TDN) and protein levels. Millets may be preferred over some sorghums for pasturing or green chop because they do not contain prussic acid. Millets and sorghums can be easily damaged by grazing and therefore should be strip grazed.

Pearl Millet

Pearl millet grows with a mass of very fine fibrous secondary roots and tillers. It exhibits drought tolerance and prefers a lighter sand or sandy loam. Sorghums will yield better on heavier soils. Pearl millet can be planted when there is no risk of frost and when soil temperatures are 12°C (54°F) or warmer. While the last week of May or early June is typically the best time to seed, planting can be delayed until the first of July. The recommended seeding rate is 9–20 kg/ha at a 1-cm (½-in.) planting depth.

Quality and quantity of forage produced will be determined by the stage of maturity when harvested. For high feed quality, first cut is usually ready about 55–60 days after planting, when it is still vegetative. Second cut is ready about 30–35 days later. Leaving at least 10 cm (4 in.) of stubble results in faster regrowth. When grazing, leave about 15–20 cm (6–8 in.) of stubble for faster regrowth.

To achieve high yields and protein levels, forage pearl millet will require more nitrogen than the older millet varieties, but exact rates have not been determined. Growth habits and yields of forage pearl millets are similar to those of sorghum-sudan hybrids. A split application of nitrogen, half at seeding and half after the first cut, will optimize yield and quality. For weed control, refer to OMAFRA Publication 75, *Guide to Weed Control.*

Sorghum Family

Members of the sorghum family used for forage include forage sorghums, sudangrass and various hybrids. There is considerable variability in agronomic and nutritional quality traits among species, hybrids and varieties.

Sorghum and Sorghum-Sudangrass

Forage sorghum and sorghum-sudangrass grow tall and have the potential for high yields. Older forage sorghum varieties were adapted to a high yield, lower forage quality, single-cut harvest. Grain sorghums, also called milo, are not recommended for forage production due to low dry matter yields.

Newer forage sorghum hybrids have been developed to be grown as a short season, two-cut, high-quality forage. Hybrid forage sorghum has fine fibrous secondary roots and tillers, giving it drought tolerance characteristics. Forage sorghum will tolerate heavier soils better than pearl millet. Optimum growth of these plants occurs under hot, moist conditions.

Planting of forage sorghums should be done after the risk of frost has past and soil temperatures are above 12°C (54°F), typically the last week of May or early June. Recommended seeding rates are 15–20 kg/ha at a 1-cm (½-in.) planting depth. Fertilize with phosphorus and potash according to soil test. The nitrogen recommendation is 50–100 kg/ha. A split application of nitrogen, half at seeding and half after the first cut, will optimize yield and quality. For weed control, refer to OMAFRA Publication 75, *Guide to Weed Control.*

The stage of maturity is the most important factor influencing the quality and quantity of forage produced. Typically, forage sorghums are ready for harvesting 60–65 days after planting (late July or early August) and a second cut will be ready 30–35 days later. For a faster recovery of aftermath growth, leave at least 10 cm (4 in.) of stubble when cutting, or 15–20 cm (6–8 in.) when grazing. A one-cut silage system will greatly improve yields but at the expense of feed quality. Feed quality drops dramatically after heading. The crop should be wilted and ensiled at about 65% moisture content.

Forage sorghum varieties with brown midrib (BMR) characteristics are being developed with increased fibre digestibility. BMR is a genetic mutation that reduces the amount of lignin in the stalk and can also increase lodging.

Sudangrass

Sudangrass is used for pasturing. It has pencil-size stems and is palatable even after it heads out. Grazing should be delayed until the crop reaches 45 cm (18 in.). Under rotational grazing, the crop will remain productive and succulent throughout the season. Sudangrass can tolerate slightly wetter soils than the other sorghums but does best on medium to well-drained soils.

Prussic Acid Poisoning

Prussic acid poisoning is a possible concern if feeding sorghums, particularly with younger or frosted plants. Sorghum and sudan grasses can cause prussic acid (hydrogen cyanide) poisoning in livestock. Young or immature plants, plants suffering from drought or plants that have been frosted contain a higher level of prussic acid. Short-season areas are at greater risk of frost. High-nitrogen fertilizer also increases the potential toxicity. Some newer hybrid forage sorghums may have an advantage in lower levels of prussic acid potential. To reduce the risk of prussic acid poisoning:

- Do not graze pastures or green chop stands less than 45–60 cm (18–24 in.) tall.

- Do not green chop or ensile sorghum over 76 cm (30 in.) tall for 3 days after a killing frost.
- Do not green chop plants under 45 cm (18 in.) tall for 3 weeks after a killing frost.
- After a drought, do not graze animals on new growth following a rain.
- Use varieties with reduced prussic acid content.

Prussic acid poisoning is not a concern with millets.

Nitrate Poisoning

Abnormally high nitrate levels in forages can lead to nitrate poisoning and even death in livestock, and formation of silo gas if the crop is ensiled. Of the various forages, sudan-sorghum and cereals can accumulate the highest levels; forage grasses accumulate intermediate levels; while legumes accumulate levels low enough to rarely be considered a problem. Nitrate poisoning can also be a concern with green chop corn and corn silage.

Nitrate levels are only a problem under abnormal growing conditions, with the following situations the major concern:

- Very high soil levels of nitrogen, due to excessive rates of nitrogen fertilizer or manure or combinations of these along with legume plowdown.
- A long drought, followed by rain. In this situation, delay harvest for 10 days after rainfall, to allow conversion of nitrates to protein.
- Any condition that kills the leaves, while roots and stems remain active and accumulate nitrates (such as frost, hail and sometimes drought).

Suspect feeds can be tested for nitrate levels. Ensiling will reduce the nitrate level in the forage. Note that when high nitrate forage is ensiled, deadly nitrogen dioxide gas can be produced (see the section *Silo Gas*, on page 159).

Forage Brassicas: Forage Rape, Kale and Stubble Turnips

Forage rape, kale and stubble turnips are excellent crops for providing high-quality pasture from September to December. Refer to OMAFRA Publication 19, *Pasture Production*, for more information.

Annual Ryegrass

Annual ryegrass is a rapidly growing bunchgrass that is adapted to a wide range of soil conditions. It regrows continuously throughout the season and has the potential to be highly productive if it receives enough rain and nitrogen. It is a useful species for mid- to late-season production but does poorly under high-temperature conditions. During periods of little or no rainfall, the plants stop growing and may die.

Two types of ryegrass of differing growth habits are available.

Italian Ryegrasses

The Italian ryegrasses are short-lived perennials, but under Ontario winter conditions behave like an annual. The Italian ryegrasses remain vegetative, producing a lush, leafy growth that doesn't usually grow taller than 40 cm (16 in.). They are difficult to use for making hay.

Westerwold Ryegrasses

The Westerwold type is a true annual and grows to 40–80 cm (16–32 in.) high, making it suitable for pastures or hay crops. The Westerwold varieties grow taller, produce stems and are therefore easier to hay. Cut before or just at the heading stage. Feed quality decreases rapidly after heading.

Seed in early spring at a rate of 20–25 kg/ha using a drill or cultipacker-type seeder. The seed should be placed 1 cm deep and the seedbed rolled to ensure good emergence from the light, fluffy seed.

Table 5–2, *Characteristics of Annual Forage Crops in Ontario*, on page 141, summarizes the characteristics of annual forage crops grown in Ontario.

Mixture Selection

Soil conditions are often important in determining which species are suitable in a mixture. Usually the legumes are selected first, followed by the grasses, because legumes are often more sensitive to drainage and pH. Soil conditions such as slope or stoniness may make it desirable to seed a legume that has long-term persistence. Consult the section *Perennial Legumes*, on page 133, for more information on legume tolerance to various soil conditions (see Figure 5–1, *Soil Drainage Requirements of Forage Species*, on page 142).

Legumes are usually grown in a mixture with one or more grasses. The major advantages of a pure legume stand are that the protein and energy levels of the feed will likely be greater, quality will decline more slowly with advancing maturity, and quality will vary little from cut to cut. Unless well managed, pure legume stands can have these disadvantages:

- weedier stands
- complete loss of feed supply if winterkill is severe
- slower drying in the windrow
- more lodging

Table 5-2.
Characteristics of Annual Forage Crops in Ontario

Annual Crop	Use	Seeding Date	Seeding Rate kg/ha	N Rate kg/ha	Avg. Yield TDM/ha	Harvest Maturity
Oats	Pasture Green chop Hay Silage	April–August	80–100	30–50	2.5–4.5 5.5–8.5	Late boot to early head Heads emerged to soft dough
Barley	Green chop Silage	April–June	100–125	40–70	2.5–5.5 5.5–9.5	Late boot to early head Heads emerged to soft dough
Oats + peas or Triticale + peas	Silage	April–June	Oats or triticale: 80–100 peas: 50–75	20–30	2.5–5.0 6.0–9.0	Late boot to early head Heads emerged to soft dough
Fall rye	Pasture	August 15–31	150	50–80 In spring	1.0–1.5	Graze 7 wk after seeding or early spring
Winter triticale	Pasture	August 25–Sept. 10	100–125	80 In spring	1.0–1.25	Graze 7 wk after seeding or early spring
Soybeans	Silage	May 20–June 10	80–100	None	6.0–9.0	Lower leaf turns yellow
Annual alfalfa	Hay Silage	Late April	13	None	6.0–12.0	Late bud stage, 5–6 wk after a cut
Sudan grass	Pasture	June 1–15	15–20	30–50	5.0–7.0	45 cm in height
Sorgum-sudan hybrids	Pasture Green chop Silage	June 1–15	15–20	50–100	8.0–12.0	Boot or early heading
Forage sorghums	Silage Pasture Green chop	June 1–15	13–20	100	7.0–9.0	Boot or early heading
Millet	Silage Pasture Green chop Hay	June 1–15	14–20	35–55	4.0–6.0	Boot or early heading
Pearl millet	Silage Pasture Green chop Hay	June 1–15	9–20		4.0–12.0	Boot or early heading
Forage rape	Pasture Green chop	July 1–15	2–6	45–70	7.0–9.0	10–12 wk after seeding
Kale	Pasture Green chop	June–July	2–6	45–70	9.0–12.0	10–15 wk after seeding
Stubble turnips	Pasture	July 1–15	2–6	80–100	6.0–9.0	10–12 wk after seeding
Annual ryegrass	Pasture Green chop Hay Silage	April–May	20–30	Use rates from Table 5-7, on page 148	8.0–12.0	Graze or cut 6–8 wk after seeding

100 kg/ha = 90 lb/ac

- under some conditions, less palatable feed

When selecting the grass, a major consideration should be the maturity of the grass. If early heading species such as orchardgrass and reed canarygrass are used, then harvesting must be early, or quality and palatability suffer. If harvesting will be later, a later-maturing grass such as timothy is more suitable. Since there is a range in maturity among different varieties within many species, variety maturity may also need to be considered.

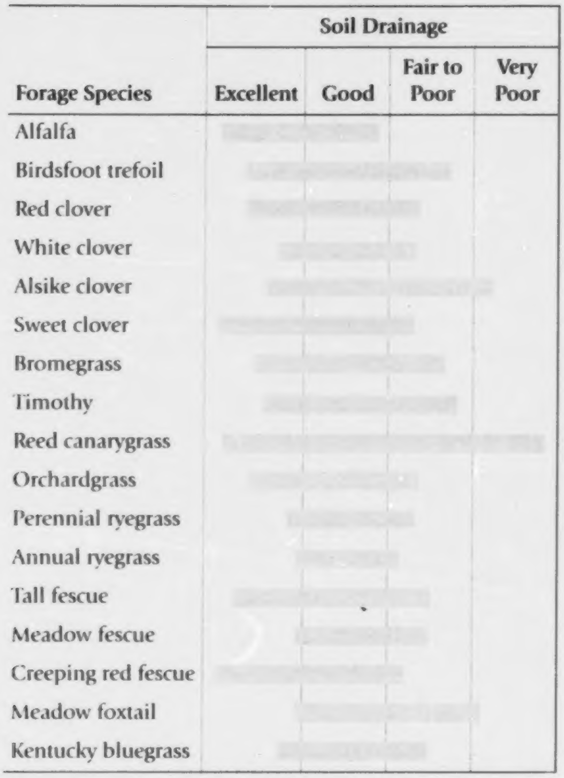


FIGURE 5-1.
Soil Drainage Requirements of Forage Species

Consider the ratio of grass to legume desired in the mixture. If more grass is desired and a lower protein level is acceptable, as it would be, for example, for beef cow-calf forage, use a higher grass seeding rate. Higher grass rates tend to reduce weed invasions, particularly by dandelions. If conditions for legume survival are marginal, use higher grass rates for stand insurance. More aggressive grasses, such as orchardgrass, will give more grass in the mixture than less aggressive species even when similar seeding rates are used.

Table 5-3, *Recommended Forage Mixtures for Stored Feed and Pasture,* on page 143, summarizes the characteristics of the perennial forage species and mixtures grown in Ontario.

For many years, timothy has been the grass of choice when grown in mixtures with alfalfa, red clover and birdsfoot trefoil. This reflects the ease of seeding, relatively low seed cost, lack of crowding of the legume and later maturity of timothy, which make it easy to manage in mixtures. In specific situations, the other grasses can give better results than timothy but often require somewhat different management. Timothy does not crowd alfalfa, in fact, under a three-cut system, it often declines in the stand and provides very little forage in second or third cuts. Orchardgrass provides more midsummer grass in alfalfa mixtures than timothy. If a strong grass component is desired in the mixture, particularly in second and third cuts, then orchardgrass should be used; it is an aggressive grass and will crowd alfalfa as the stand gets older. Bromegrass and reed canarygrass are intermediate in aggressiveness (between timothy and orchardgrass).

Management can effect the competitiveness of grasses with legumes. Late harvest, when grasses are in bloom, favours the grasses relative to the legumes. This is particularly true with reed canarygrass. Cut at the boot stage, reed canarygrass does not crowd legumes. But if allowed to fully head, it rapidly takes over the stand. It is particularly important in birdsfoot trefoil mixtures, if bromegrass or reed canarygrass are used, to harvest promptly at the grass boot stage. If this is not possible or practical, then timothy is a more suitable grass.

Grasses are not usually grown in pure stands because they are low yielding without heavy applications of nitrogen (See the section *Fertility Management*, on page 148). Even with adequate fertility, some grass species produce low yields under hot, dry midsummer conditions. However, if soil conditions such as poor drainage make mixtures with legumes impractical, pure grass stands can be very productive with proper fertility programs and species selection. Pure grass stands may be more productive than grass-legume mixtures in some areas of northern Ontario.

For stored feed, usually only one grass species is recommended. When two or three different species are used together, cutting at the proper stage of maturity for all grasses may be impossible. Timothy is often included with slow-establishing grasses such as bromegrass and reed canarygrass.

Variety Selection

Forage varieties are evaluated each year in tests conducted at a number of locations across Ontario. The results are published in the brochure, *Ontario Forage Crop Variety Performance*, available from OMAFRA or on the Internet at http://www.plant.uoguelph.ca/performance_recommendations/ofcc/ofcc.htm.

This brochure provides information on the yield performance of recommended varieties relative to well-known reference varieties. Information is also provided on other factors, including persistence, intake potential, fibre digestibility, disease and insect resistance, maturity and regrowth rate.

Table 5-3.
Recommended Forage Mixtures for Stored Feed and Pasture

Components	Seeding Rate[1] kg/ha	Recommended for			Specific Recommendations
		Stored Feed	Managed Pasture	Intensively Pastured	
1. Alfalfa	13	X			Only on well-drained fields where alfalfa persists well. Easier to cure as silage than as hay. Harvest at bud stage for high-quality feed.
2. Alfalfa Timothy	13 1	X			Increase timothy up to 4 kg/ha for higher grass content and easier curing. Timothy gives stand insurance in areas prone to alfalfa winterkill. For high-quality feed, harvest with timothy in boot stage. On severely dry soils or in areas with over 3,100 CHUs, bromegrass is preferable to timothy.
3. Alfalfa Bromegrass	11 9	X			Will give somewhat better midsummer production than timothy mixture. Retains quality with increasing maturity better than orchardgrass or timothy mixtures. Because of rhizomes, bromegrass can thicken stand over time.
4. Alfalfa Orchardgrass	11 2	X		X	Select late orchardgrass and early alfalfa varieties. Graze or cut early to maintain quality and palatability. Percentage grass higher in all cuts than with timothy or bromegrass mixtures.
5. Alfalfa Orchardgrass White clover	9 2 2	X		X	Same as 4. High fertility and good grazing management needed for top production. Alfalfa included as insurance against severe dry conditions, but requires longer regrowth intervals to persist.
6. Alfalfa Timothy Bromegrass White clover	9 4 9 2	X		X	Suitable for hay/pasture combinations.
7. Birdsfoot trefoil Timothy	9 2	X	X		Use later-maturing timothy varieties.
8. Birdsfoot trefoil Bromegrass	9 4	X	X		For long-term stands and early production. Graze early to reduce competition from bromegrass. Good brome growth in fall.
9. Birdsfoot trefoil Orchard	8 4			X	Good early and mid-season production. Graze down orchardgrass to reduce competition with birdsfoot trefoil. Later-maturing orchardgrass varieties are preferred.
10. Birdsfoot trefoil Tall fescue[2]	8 10	X	X	X	Good production throughout the season. Good tall fescue growth and quality in the fall.
11. Birdsfoot trefoil Creeping red fescue	8 6		X		Good summer and fall production. Excellent quality in fall.
12. Red clover	11	X			Short-term hay production or plowdown crop.
13. Red clover Timothy	7 6	X			Short-term production. When clover disappears, plow or fertilize with nitrogen to maintain production.
14. White clover Orchardgrass	2 9			X	For pasture use where white clover is adapted. High fertility, adequate moisture and good grazing management required for top production. In dry areas, add alfalfa (see 5 above).

[1] For early seeding on a fine, firm seedbed, these rates may be reduced by 25% except where coated seed is being used.

[2] Use endohyte-free seeds.

All forage seed sold under a variety name must be labelled "certified seed" and have a blue tag verifying it. This ensures that the seed is the name variety. Certified seed must meet specific requirements for germination and weed seed content.

Forage seed may also be sold as common seed or as a brand. Common seed and brands may be blends of different seed lots. They also must meet requirements for germination and weed seed content, but these are less rigorous than for certified seed. No assurance of characteristics such as disease resistance or hardiness is possible for common seed. Thus the performance of stands established using common seed or brands is unpredictable, and will often vary from year to year. The use of pedigree seed, rather than brands or common seed, is strongly recommended. Only by planting varieties is it possible to know in advance whether the seed you plant will provide the yield, persistence, disease resistance and maturity that is required for your specific fields and farm operation.

Tillage

Seedbed Preparation

The goal of tillage is threefold:

1. To produce a firm, level seedbed that allows good control of seeding depth.
2. To produce a fine seedbed that permits good soil to seed contact.
3. To produce a smooth surface for the harvesting operations.

Forage seed is very small, making good seed-to-soil contact essential for germination, particularly in dry conditions. A loose, lumpy seedbed dries out quickly, and lumps make the emergence of young seedlings difficult. Soil should be firm enough at planting for a footprint to sink no deeper than 9 mm ($^3/_8$ in.). Packing before seeding can help, especially on sandy loam soils where a disc produces a "fluffy" seedbed. Packing should be done shortly after seeding to prevent excessive moisture loss. On clay loam soils, forage establishment is most reliable when the field has been fall plowed. Freezing and thawing action on these soils result in easier preparation of a fine seedbed the following spring.

Heavier soils plowed in the spring often require excessive tillage to produce a fine seedbed. If soils are worked too fine, a surface crust could reduce emergence after a heavy rainfall, while also increasing erosion potential and decreasing water infiltration.

No-till seeding of forages has been quite successful where the soil conditions following the previous crop were smooth and level. The biggest risk factor to no-till seeding of forages is slug damage where surface residue is heavy.

Land susceptible to erosion will benefit from increased surface residue. However, seeding equipment must be able to handle the increased residue left by reduced tillage systems without compromising seed placement.

Establishment (Planting)

When selecting a field, consider whether it is suitable for the mixture you wish to plant. If there are limitations such as low pH, poor drainage or weed problems, such as quackgrass, these should be corrected prior to seeding.

Seeding Time

Spring Seeding

The most reliable time to seed forages is early spring, regardless of whether the crop is direct-seeded or under a companion crop. With a spring seeding, moisture is usually adequate, and the plants are well established for winter survival. Seed as early as a seedbed can be prepared to increase the chances of adequate and frequent moisture during the critical germination period.

Summer Seeding

Summer seeding can be a viable alternative to spring seeding. A summer seeding can typically follow winter or spring cereal harvest. Companion crops are not recommended in summer seedings because they compete too strongly for available soil moisture. Summer seedings can work well on lighter soils but present a higher risk on heavier soils.

Important considerations for successful summer seeding are:

Seeding Date

Seeding too early in the summer increases the risk of hot, dry conditions during germination and seedling development. Seeding too late increases the chance of freeze-up before legume seedlings are adequately established and accumulate enough root reserves to survive the winter. Legumes seeded in September or October rarely survive the winter. Alfalfa needs approximately 6 weeks' growth after germination to survive the winter and will generally survive if the crown develops before a killing frost. Small legume plants are more susceptible to winter heaving. Even if these plants survive, they will be slower starting and lower yielding.

Table 5-4.
Recommended Seeding Rates for Pure Grass Stands

Species	Seeding Rate kg/ha[1]
Timothy	8–10
Bromegrass	10–14
Orchardgrass	8–10
Reed canarygrass	10–12
Tall and meadow fescue	9–11
Meadow fescue[2]	10–12
Perennial ryegrass	10–15

[1] For early seeding on a fine, firm seedbed, these rates may be reduced by 25%, except where coated seed is being used.

[2] Use coated seed. Seed through the grain seed box.

Summer seeding should take place before the following dates:

- more than 2,900 CHUs — August 10–20
- 2,500 to 2,900 CHUs — August 1–10
- less than 2,500 CHUs — July 20–30

Birdsfoot trefoil has slow seedling development, so summer seedings are usually unsuccessful. September seeding of straight grasses may be successful, with the exception of reed canarygrass, as it is slow to establish and should not be summer seeded.

Seedbed Preparation

Seed to soil contact is particularly important in dry summer conditions. A loose, lumpy seedbed dries out quickly. Packing can help preserve moisture. A fine seedbed can be more difficult to prepare in August on clay loam soils, compared to loams, sandy loams and silt loams.

Heaving

Avoid summer seeding on heavier soils that have a history of alfalfa heaving.

Weed Control

Winter annual weeds can be a common problem, and herbicide application may be required. Refer to OMAFRA Publication 75, *Guide to Weed Control*. Caution must be used to avoid delaying growth due to a herbicide effect.

Volunteer Grain

Volunteer grain, because it may be thick and competitive, can be a serious problem in summer seedings. Oats or barley will winterkill in November, but winter wheat will be present until the first cut the following year. Tillage can be used to reduce the problem of volunteer cereals. There are herbicides that will kill volunteer cereals, but forage grasses in the mixture will be stressed or may also be killed.

Table 5-5.
Approximate Seeds per Kilogram of Various Forage Species

Crop	Seeds per kg	Seeds per pound
Alfalfa	440,000	200,000
Red clover	605,000	274,000
White clover	1,760,000	798,000
Birdsfoot trefoil	935,000	424,000
Sweet clover	572,000	259,000
Alsike	1,540,000	699,000
Timothy	2,706,000	1,227,000
Orchardgrass	1,439,000	653,000
Bromegrass	300,000	136,000
Meadow and tall fescue	506,000	230,000
Perennial ryegrass	500,000	227,000
Reed canarygrass	1,173,000	532,000
Bluegrass	4,790,000	2,173,000

No-Till

No-till summer seeding can be successful if proper attention is paid to residue management, seed placement and weed control. However, using no-till to reseed an existing alfalfa field in August is not recommended due to alfalfa autotoxicity, slugs and disease that may exist in the old sod.

Seeding Rates and Depth

The amount of seed recommended in Table 5-3, *Recommended Forage Mixtures for Stored Feed and Pasture*, on page 143, and Table 5-4, *Recommended Seeding Rates for Pure Grass Stands*, left, is intended for average to good conditions. Under excellent management and favourable conditions for establishment, these rates may be reduced by 25%. When coated seed is used, do not reduce these rates, because coated seed contains fewer seeds per unit weight. Do not expect very high seeding rates to compensate for poor conditions (a rough seedbed, heavy companion crop, etc.).

Seed size can vary between varieties and between seed lots of the same variety. Seeder calibration can help avoid over- or under-seeding. See Table 5-5, *Approximate Seeds per Kilogram of Various Forage Species*, above.

ESTABLISHMENT (PLANTING)

> As a rule of thumb, seeding depth for most forages should be 6–12 mm (¼–½ in.) on clay and loam soils, and 12–18 mm (½–¾ in.) on sandy soils.

Percentage emergence declines rapidly if forage seeds are planted more than 20 mm (¾ in.) deep. Legume seed on the soil surface may establish if moisture conditions following seeding are ideal. Success of surface seeding is much greater with late March-to-early April seedings than in late April or May.

Seeding Equipment

Grain Drill

The grain drill with a grass seed attachment is a very satisfactory method of seeding forages. The standard grass seed box will handle legume seeds and smaller grass seeds such as timothy and reed canarygrass. Some drills have an additional seed box designed to seed coarser grasses, such as bromegrass and orchardgrass, which do not flow well through the standard box.

Most drills have drop pipes attached to the grass seed box. Align the drop pipes so that seed is dropped in a row over the fertilizer placed by the disc opener. The seed should be dropped 25–35 cm (10–14 in.) behind the disc opener to allow some soil to cover the fertilizer band before the seed is dropped. This placement also ensures that the seed is not planted too deep.

Packing the soil after planting can result in a more even germination, particularly during dry springs. Press wheels help cover the forage seeds and firm the soil around the seed.

If press wheels are not available, very satisfactory results can be obtained by pulling a packer or rubber tire roller behind the drill to firm the soil. Do not use a packer if the soil is wet, particularly on clay loam soils, where crusting can be a problem.

Packer Seeders

Packer seeders, such as Brillion seeders, can be successfully used to seed forages and are equipped with both fine and coarse seed boxes. The first roller firms, levels and grooves the soil, and the seed is then dropped on this surface. The second roller covers the seed with soil and firms it around the seed. This type of seeder does an excellent job of controlling seed depth and firming the seedbed. It does not apply fertilizer and thus does not produce the starter effect achieved with the grain drill-band seeding method. This is a disadvantage mainly at low and medium soil phosphorus levels.

Broadcast Seeders

Broadcast seeders are also used to seed forages. Their main advantage is speed of seeding. There are two types of broadcast seeders and with both, control of seeding depth is a problem. Packing is necessary to cover the seed.

Seeders that use spinners can give uneven distribution, particularly under windy conditions or with seed mixtures containing light and heavy seeds. This seeding method usually results in inferior stands and is not recommended.

Air-flow boom seeders overcome the problems of wind and seed segregation while still permitting very rapid seeding.

No-Till Drills

This seeding system for forages can work well, but in some situations can fail. To avoid stand failures, follow these guidelines:

- Practise proper residue management, seed placement and weed control.
- Eliminate perennial grass weeds, including quackgrass, before seeding.
- Plant no deeper than 18 mm (¾ in.) on lighter soils or 12 mm (½ in.) on clay loam soils.
- No-till spring seedings into soybean, cereal and corn residues for the most reliable results. Remove straw from the previous crop to improve seed placement.
- Kill the sod for spring seeding legumes into existing sod the fall before. Avoid top growth of more than 15 cm at spraying time to reduce the risk of insects, disease and alfalfa autotoxicity (see the section *Alfalfa Autotoxicity*, on page 147).
- Avoid liquid manure application.

Seeding With a Companion Crop

Much of the forage acreage in Ontario is seeded under a companion grain crop that suppresses annual grass weeds and gives fairly rapid protection from erosion on rolling land. The disadvantage of a companion crop is that it competes with the forages for moisture, light and fertility. If any of these items are deficient, the forage seeding will suffer before the grain crop does.

Harvesting the Companion Crop as Grain

This system of seeding provides a grain crop and a crop of straw while the forage crop is being established. Competition from the grain crop can reduce forage establishment and subsequent yields. Lodging of the companion crop due to excess nitrogen can be a real threat to forage establishment. One should recognize that the primary purpose of the seeding is to establish the forage, while grain and straw production are of secondary importance.

Recommended guidelines:

- Oats, barley or mixed grains are commonly used as companion crops. Spring wheat or spring triticale can also be used as a companion crop and generally provide less competition to the forage seeding. Six-row barley is preferable to 2-row barley.
- As a general rule, select the strongest-strawed, shortest and earliest grain variety in any species for the least competition.
- Reduce the spring grain seeding rate to 60–70 kg/ha.
- Reduce the nitrogen fertilizer or manure rate to minimize the risk of a dense grain crop and lodging. Under most conditions, do not apply more than 15 kg/ha of nitrogen on spring grains.

Harvesting the Companion Crop as Silage

Some of the problems associated with seeding under grain can be eliminated by harvesting the grain crop as silage. Match stage of cutting to livestock nutritional requirements. For high feed quality, cereals should be harvested at the late boot stage. Delaying harvest to the fully headed stage will increase yield but reduce forage quality.

Harvesting the companion crop as silage allows weed suppression and erosion control, but the companion crop is removed before it lodges or competes excessively for light and moisture. In this situation, both the seeding rate of the cereals and the nitrogen application may be the normal rate in order to increase the silage yield. With reasonable soil moisture following harvest, it is quite possible to also obtain a cut of forage in late August in areas with 2,600 heat units or more.

Direct Seeding

Seeding forages without a companion crop removes the potential threat to establishment from the grain crop. Under good management, direct-seeded forage stands are often thicker and more uniform. This is particularly true of forage species such as birdsfoot trefoil, alfalfa and reed canarygrass, which do not tolerate heavy shade. Since a grain crop is not competing for soil moisture, direct seedings are less affected by June or July droughts.

Early spring direct seedings can be expected to give one or two cuts of forage in the seeding year, yielding 50%–60% of an established stand. Direct-seeded forages are useful when the harvested forage acreage must be increased on short notice to compensate for winterkill or increased forage requirements.

Direct seedings have been most popular in Ontario:

- on silt loam, loam and sandy loam soils
- with birdsfoot trefoil- or alfalfa-based mixtures
- on dairy farms where nitrogen build-up from livestock manure frequently results in cereal grain lodging
- where other crops provide the grain and straw requirements

Direct seedings have not met with success on all farms. Weed competition is a greater problem with direct seeding than with under-seeding. (see the section *Weed Control*, on page 161).

In the year of seeding, the root systems of forage crops are shallow and therefore more vulnerable to drought than established stands. Droughts can reduce production to one cut rather than two but do not usually reduce the stand.

Direct seedings on heavier clay loam soils require more skillful seedbed preparation and seeding. Clay soils, particularly where the seedbed is somewhat lumpy, are more vulnerable to dry conditions during germination, thereby reducing establishment. They also are more vulnerable to crusting and seedling emergence problems if heavy rains follow seeding.

Alfalfa Autotoxicity

Seeding alfalfa after alfalfa is high risk because old stands of alfalfa release a toxin that reduces germination, root development and growth of new alfalfa seedlings. This is called autotoxicity. Roots are swollen, curled, discoloured and lack root hairs. The negative effects on root growth can significantly impact yields.

Germination and establishment problems (plant density) result when the existing stand is not killed at least 2 or 3 weeks before reseeding. More importantly, these toxins are present for up to 6 months, which are sufficient to permanently reduce new stand yields. For maximum yields, if the alfalfa is 2 or more years old, an intervening year of an alternate crop is required before reseeding to alfalfa.

Table 5-6.
General Nitrogen Recommendations – Perennial Forages

Crops	N Required kg/ha
Legume or legume-grass at seeding	
Without a nurse crop	0
With a nurse crop	15
Unimproved pasture	50
Grass for seed	90
Hay or pasture	
1/2 or more legumes	0
1/3 to 1/2 legumes	60
Grass (less than 1/3 legume)	(See Table 5-7, right.)

100 kg/ha = 90 lb/ac

The toxins are not present the first year in new seedings, so seeding failures or new seeds that were winterkilled can be reseeded without an autotoxicity effect. This would include a summer seeding after an unsuccessful spring seeding or a spring seeding after an unsuccessful summer seeding.

It is not recommended that interseeding be done to thicken an established alfalfa stand, as this is rarely successful. New seedlings often germinate, look acceptable early and then die out over the summer. Thin spots can sometimes be interseeded with red clover instead.

Inoculation

For normal growth, all legumes must have nitrogen-producing nodules on their root systems. These nodules are produced by *Rhizobium* bacteria.

Legume species (alfalfa, clover, birdsfoot trefoil) require their own specific strain of *Rhizobium* for proper nodulation. If a legume is being planted for the first time in a field, the seed must be inoculated with the proper strain of *Rhizobium* bacteria before planting. Pre-inoculated seed is satisfactory, provided that the inoculant is applied in the current season. Since the inoculant must be alive, note the expiry date and handling precautions on the packet to ensure effective nitrogen fixation. When a forage legume species has routinely been grown in a field as part of the rotation, these bacteria are usually present in the soil and should result in good nodulation. The cost of the *Rhizobia* is low in comparison to the cost of seed. If there is any doubt about the presence of rhizobia in the soil, the seed should be inoculated.

Table 5-7.
Nitrogen Recommendations for Improved Grass Hay or Pasture

Value of Hay ($/tonne)	Application No.[1]	Cost of Nitrogen Fertilizer			
		$60/ kg	$70/ kg	$80/ kg	$90/ kg
		N required[2] (kg/ha)			
30	1	95	75	70	70
	2	75	60	50	35
	3	60	50	40	30
50	1	130	125	115	105
	2	105	100	90	80
	3	85	80	70	65
70	1	150	140	135	130
	2	120	115	110	100
	3	95	90	85	80

100 kg/ha = 90 lb/ac

[1] First application to be made prior to May 10. Second application to be made after the first cut. Third application to be made after the second cut only if there is reasonable assurance of a third cut.

[2] For stored feed: Where manure is applied, reduce the fertilizer application according to the type and amount of manure (see the section *Manure*, on page 20). For pasture: All rates should be reduced by one-third because of recycling through manure and urine.

Fertility Management

Nitrogen

Forage stands that are more than 50% legume do not require nitrogen fertilizers. For nitrogen recommendations, refer to Table 5-6, *General Nitrogen Recommendations – Perennial Forages*, left, and Table 5-7, *Nitrogen Recommendations for Improved Grass Hay or Pasture*, above.

Grass stands containing less than one-third legume require large amounts of nitrogen to optimize yield. Where conditions permit, it is generally more profitable to reseed to mixtures containing legumes. It can be profitable to fertilize grass stands consisting of productive species such as bromegrass, orchardgrass or timothy. The use of nitrogen will also increase the protein level in the grass. The rates of nitrogen recommended for grass stands have been developed on the basis of the price of nitrogen relative to the value of hay (see Table 5-7, above). The first application for hay or pasture should be made as early as possible in the spring, followed by a second application after the first cutting and a third application after the second

Table 5-8.
Phosphate Recommendations for Forages Based on OMAFRA-Accredited Soil Tests

Sodium Bicarbonate Phosphorus Soil Test (ppm)	At Seeding With or Without Nurse Crop		Band Seeded Without a Nurse Crop[1]		Established Stands		Unimproved Pasture	
	Rating	Phosphate (P_2O_5) Required[2] kg/ha	Rating	Phosphate (P_2O_5) Required[2] kg/ha	Rating	Phosphate (P_2O_5) Required[2] kg/ha	Rating	Phosphate (P_2O_5) Required[2] kg/ha
0-3	LOW	130	LOW	130	LOW	180	LOW	70
4-5		110		110		120		60
6-7		90		90		90		50
8-9		70		70		60		30
10-12	MEDIUM	50	MEDIUM	50	MEDIUM	30	MEDIUM	20
13-15		30		40		20		20
16-20		20		30	HIGH	0	HIGH	0
21-25		20		20		0		0
26-30	HIGH	0	HIGH	20	VERY HIGH	0		0
31-40		0		20		0	VERY HIGH	0
41-50	VERY HIGH	0		20		0		0
51-60		0	VERY HIGH	0		0		0
61+	EXCESSIVE[3]	0	EXCESSIVE[3]	0	EXCESSIVE[3]	0	EXCESSIVE[3]	0

100 kg/ha = 90 lb/ac

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[1] For use only where seed is banded directly above the drilled fertilizer.

[2] Where manure is applied, reduce the fertilizer application according to the amount and quality of manure (see the section *Manure*, on page 20).

[3] A rating of "Excessive" may mean reduced yield or affected nutrient balance in crops and increased risk of nitrate movement into groundwater.

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cutting. To avoid the danger of nitrate toxicity, no more than 170 kg of nitrogen/ha should be applied at any one time.

Nitrogen deficiency in forages shows up as a general yellowing and stunting of the plants. It may show in the lower parts of the plants first. In legumes, a nitrogen deficiency usually indicates poor nodulation, and/or low soil pH.

Phosphate and Potash

Phosphate and potash recommendations are given in Table 5-8, *Phosphate Recommendations for Forages Based on OMAFRA-Accredited Soil Tests*, above, and Table 5-9, *Potash Requirements for Forages Based on OMAFRA-Accredited Soil Tests*, on page 150. For information on the use of these tables or if you do not have an OMAFRA-accredited soil test, refer to the section *Fertilizer Recommendations*, on page 31.

When direct-seeding on soils that require phosphate fertilizer, establishment may be improved by the placement of a high phosphate fertilizer 5 cm directly below the seed. Using a grain drill with fertilizer and grass seed attachments, this placement may be accomplished by drilling the fertilizer through the furrow opener and dropping the forage seed on a firm soil surface directly behind the furrow opener. Usually it is advisable to firm the soil surface immediately after seeding.

Potash may be more effective in promoting persistence if it is applied within the 6 weeks before the start of the fall rest period. Potash deficiency is occasionally found in alfalfa, showing symptoms of small, light dots on the leaflets. These dots can be on any part of the leaflet but are usually concentrated near the margins (see Plate 87 on page 289). Grasses and clovers are much less likely to show potash deficiency symptoms. Phosphate, if required, may be applied with the potash or at other times of the year. Phosphate deficiency symptoms are rare and non-specific in forages, but a short-

Table 5-9.
Potash Requirements for Forages Based on OMAFRA-Accredited Soil Tests

Ammonium Acetate Potassium Soil Test (ppm)	At Seeding With or Without Nurse Crop		Fall Applications for New Seeding and Established Stands	
	Rating	Potash (K_2O)[1] Required kg/ha	Rating	Potash (K_2O)[1] Required kg/ha
0–15	LOW	90	LOW	480
16–30		80		400
31–45		70		320
46–60		50		270
61–80		40		200
81–100		30		130
101–120	MEDIUM	20	MEDIUM	70
121–150		20		20
151–180	HIGH	0	HIGH	0
181–250	VERY HIGH	0	VERY HIGH	0
251+	EXCESSIVE[2]	0	EXCESSIVE[2]	0

100 kg/ha = 90 lb/ac

[1] Where manure is applied, reduce the fertilizer according to the amount and quality of manure (see the section *Manure*, on page 20).

[2] A rating of "Excessive" may mean reduced yield or quality of crops primarily due to magnesium deficiency. Natural levels above 251 occur occasional on clay and clay loam soils but are not expected to cause problems because soils naturally high in potassium are usually also high in magnesium.

age of phosphate may manifest itself as stunting and poor winter survival of legumes.

Plant Analysis

When analyzing forage legumes, sample each species separately. Cut the plant at normal mowing height at the late bud stage. See Table 5-10, *Interpretation of Plant Analysis for Alfalfa*, right. However, plants suspected of nutrient deficiency should be sampled as soon as the problem appears. For sampling at times other than heading, and for species other than alfalfa, samples should be taken from both deficient and healthy areas of the field for comparative purposes. A soil sample should be taken from the same area and at the same time as the plant sample.

Table 5-10.
Interpretation of Plant Analysis for Alfalfa

Nutrient	Units	Critical Concentration[1]	Maximum Normal Concentration[2]
Nitrogen (N)	%	–	5.5
Phosphorus (P)	%	0.20	0.5
Potassium (K)	%	1.70	3.5
Calcium (Ca)	%	–	4.0
Magnesium (Mg)	%	0.20	1.0
Sulphur (S)	%	0.22	–
Boron (B)	ppm	20.0	90.0
Copper (Cu)	ppm	5.0	30.0
Manganese (Mn)	ppm	20.0	100.0
Molybdenum (Mo)	ppm	0.5	5.0
Zinc (Zn)	Ppm	10.0	70.0

Values apply to the plant cut at normal mowing height at the late bud stage.

[1] Yield loss due to nutrient deficiency is expected with nutrient concentrations at or below the "critical" concentration.

[2] Maximum normal concentrations are more than adequate but do not necessarily cause toxicities.

Micronutrients

Boron

Boron is important for alfalfa, however its application is not required on all soils. A deficiency shows up mainly on high pH, sandy soils. Boron applications are recommended on all sandy soils and, in particular, the sandy loam and loam soils in the area east of the Niagara Escarpment up to and including Frontenac county. Boron deficiency is seen most frequently on droughty soils under dry conditions.

A shortage of available boron to the alfalfa plant first affects flowering and reduces seed-set. As the deficiency becomes more serious, the youngest upper leaves of the plant become yellow to red in different plants (see Plate 88 on page 289). Growth can be severely stunted and winter hardiness reduced.

Boron deficiency can usually be corrected or prevented by an application of 1.0–2.0 kg boron/ha broadcast annually. Boron should not be banded at seeding.

Mixtures of herbicides and fertilizers should not be applied to crop foliage unless recommended by competent authorities. For further details on boron deficiency and on methods of application, refer to the

OMAFRA Factsheet, *Boron Fertilization of Alfalfa*, Order No. 86-056, or visit the Web site at www.gov.on.ca/OMAFRA/english/crops/field/forages.

Sulphur

Sulphur deficiency has not been observed in forages in most of Ontario. The sulphur in acid precipitation falling on Northeastern and Southern Ontario is sufficient for crop requirements. There have been scattered reports of sulphur deficiency in alfalfa in Northwestern Ontario on sandy soils with low organic matter. The appearance of sulphur deficiency is similar to nitrogen deficiency with general yellowing of the plants.

Other Micronutrients

Deficiencies of copper, zinc or manganese have not been observed in forages in Ontario.

Manure

Manure is an excellent source of nutrients and can substitute for manufactured fertilizers. It is an excellent source of nitrogen for grasses, but forage legumes do not make efficient use of manure nitrogen. Do not apply manure to perennial forage legumes when there is snow cover, because ice frequently forms under the manure and can kill the plants (see the section *Manure*, on page 20).

Liming

Legumes generally are not tolerant of acid soil conditions. Acid soils should be limed 1 year before seeding at rates indicated by soil tests. (See the section *Soil Acidity and Liming*, on page 31.) Applying lime to established stands is not normally profitable.

Harvest and Storage

Forage Quality

The type of livestock being fed determines the appropriate quality of forage. Match forage quality to the nutritional requirements of the animal. For a high-producing dairy herd, quality feed, which is high in digestible energy and protein must be produced. The benchmark analysis for alfalfa for high-producing dairy cows is considered to be 20% crude protein (CP), 30% acid detergent fibre (ADF), and 40% neutral detergent fibre (NDF). For a beef cow, the most appropriate hay is more mature and higher yielding, and is therefore lower in protein and digestibility. Many recreational horse owners prefer hay that is more mature and contains more grass than is common in dairy hay, but it is very important that it be entirely free of mould and dust. Some markets also require the hay to be green in appearance and entirely free of weeds. The remainder of this section will use the term "high quality" to mean high in protein and digestible energy.

Laboratory analyses of forages is essential for accurate ration formulation. The nutrient content of forages varies greatly depending on the type, stage of maturity at cutting and how well it is preserved.

Forage Nutrition Terms Defined

As-Fed Basis

An expression of feed nutrient content with the moisture included. Nutrient content on an "as-fed" basis is always lower than on a "dry-matter" basis.

Dry-Matter Basis

An expression of feed nutrient content after the moisture has been removed by drying. Used to compare nutrient composition or animal intake of feeds differing in moisture content.

Crude Protein (CP)

An estimate of the total protein content of a feed. Determined by analyzing the nitrogen content of the feed and multiplying the result by 6.25. Crude protein includes true protein and other nitrogen-containing substances such as ammonia, amino acids and nitrates.

Acid Detergent Fibre (ADF)

The amount of residue (primarily cellulose and lignin) left after boiling a feed sample in an acid detergent solution. The ADF value is used to predict the energy content (TDN, NE) of forages.

Neutral Detergent Fibre (NDF)

The insoluble fraction containing all plant cell wall components left after boiling a feed sample in a neutral detergent solution (primarily hemicellulose, cellulose and lignin). NDF is used to predict ruminant feed intake.

Relative Feed Value (RFV)

RFV is calculated using ADF and NDF. The relative feed value for grasses is usually lower than for legume forages, due to the higher fibre values. For this reason, it is questionable to compare the relative feed value of different species.

Net Energy (NE)

The amount of feed energy actually available for animal maintenance and production. It represents the energy fraction in a feed left after fecal, urinary, gas and heat losses are deducted from the gross energy value of a feed.

Total Digestible Nutrients (TDN)

A term describing the energy value of feedstuffs using regression equations.

Acid Detergent Fibre–Nitrogen (ADF-N)

A laboratory test used to measure the amount of heat-damaged protein in hay and haylage.

In Vitro Digestibility (IVD)

A measure where a forage sample is incubated in rumen fluid for a given period of time to simulate digestibility in rumen conditions.

Fibre Digestibility (dNDF)

The digestibility of the fibre is determined by in vitro NDF digestibility. This impacts both digestible energy of the forage and animal intake.

Fermentation Profile

Fermentation profile analysis is available for silage to determine relative amounts of lactic, acetic, butyric, propionic acids and pH.

Measuring Corn Silage Digestible Energy

Corn silage is unique in that it consists of a mixture of two very different components — high moisture grain corn and stover. High digestible energy is important to reduce the need for supplemental grain. Lower NDF and increased dNDF are important for increased intake, as well as energy.

Digestible energy of corn silage is primarily determined by the relative amounts of starch and fibre (NDF) and their digestibilities. ADF is sometimes used to estimate energy, and NDF is used to estimate intake, but these measures alone do not consider digestibility. Newer methods more accurately estimate corn silage digestible energy using CP, fat, nonstructural carbohydrates (NSC), NDF and lignin. Other methods are used that also use starch and in vitro NDF digestibility (dNDF). Kernel texture, moisture and processing influence starch digestibility.

Table 5–11.
Digestibility and Protein of Alfalfa and Bromegrass at Various Stages of Maturity

		% Digestibility		% Crude Protein	
Stage of Maturity	**Date**	**Alfalfa**	**Bromegrass**	**Alfalfa**	**Bromegrass**
Medium bud	June 4	72.6	73.8	21.5	13.4
Early flower (heads emerged)	June 20	65.2	67.2	17.0	10.0
Full flower	June 30	62.1	60.6	16.2	6.7
Early seed	July 6	60.9	59.7	15.6	5.8

Forage Harvest Timing

The timing of the harvest is the most important consideration when trying to produce quality forage. Forage crops decline in feeding value as they mature. For instance, once alfalfa buds appear, feeding value will decline about 0.2% per day in protein and about 0.4% per day in digestibility (see Table 5–11, *Digestibility and Protein of Alfalfa and Bromegrass at Various Stages of Maturity*, above). Short delays in cutting result in significantly lower forage quality. Of course, finding a window of dry weather can complicate things even further.

> As a general rule of thumb, high-quality, first-cut forage should be cut at mid-bud to full-bud stage.

The timing of cutting is determined by the nutritional requirements of the livestock being fed.

Cutting at the pre-bud or early-bud stage will result in reduced yields and may increase the risk of losing the stand. Extremely low fibre levels may result in nutritional problems. With grasses, a compromise between yield and quality occurs at "early head emergence from the boot." Orchardgrass will mature much earlier than timothy and bromegrass. Delayed harvesting of forage will give higher yields and greater plant persistence, but lower feed quality. With a large acreage of forage, it is advisable to start cutting earlier to ensure the later cut material will still have adequate quality.

Subsequent second and third cuttings of alfalfa may be in intervals of approximately 30 days (mid-bud) to 40 days (early flower) or more, depending on whether the goal is high quality or maximum persistence and yield. (See the section *Forage Winterkill*, on page 171.)

Predicting Alfalfa Quality in a Standing Crop

Methods used to determine when to begin cutting first-cut alfalfa include the calendar date, stage of development (mid-bud, full-bud), growing degree days (GDDs) (see the section *Growing Degree Days*, on page 3), scissors cut, and the Predictive Equations for Alfalfa Quality (PEAQ). The PEAQ method uses the longest stem and the most mature stem to estimate the NDF of the alfalfa in a standing crop.

Many base cutting decisions using NDF as the primary quality variable. For high-producing dairy cows, optimum alfalfa NDF for intake and dietary fibre is approximately 40%. With warm weather, NDF can increase about 0.7 units per day, and therefore quality can drop rapidly. NDF can vary from 1 year to the next by up to10% when cutting is on the same date. The relationship between morphological stage, such as early or late bud stage, and NDF is not always high.

A PEAQ stick has been developed, that incorporates the NDF estimates onto an easy-to-read measuring stick, which can be used in the field. PEAQ is intended for use as a tool in making cutting decisions and is not meant to replace forage analysis and ration balancing. For details on how to use the PEAQ system, refer to *Predicting Alfalfa Quality Using PEAQ* on the OMAFRA Web site at www.gov.on.ca/OMAFRA/english/crops/field/forages.html.

Dry Hay

The greatest amount of feed value is stored when both field and storage losses are minimized. The amount of each loss is largely determined by the moisture content of the forage when going into storage. Storing dry hay results in high field losses but relatively small storage losses. On the other hand, storing forages as haylage gives lower field losses but higher storage losses (see Figure 5–2, *Estimated Hay and Haylage Harvest and Storage Losses*, right).

Cutting and Conditioning

Disc mowers perform more dependably than sickle mowers in situations where forage is lodged, or in very thick grass stands. Disc mowers can operate at higher speeds and may be more expensive.

Hay conditioners crush, crimp or flail the plant stems and speed up drying. Quicker drying reduces the risk of the hay being rained on, and synchronizes the drying of leaves and stems, which can reduce leaf shatter. Grasses generally dry faster than legumes.

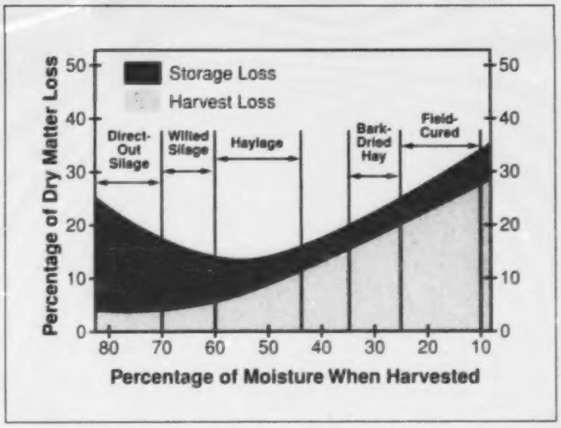

Figure 5–2.
Estimated Hay and Haylage
Harvest and Storage Losses

Adapted from Hoglund, 1964.

Windrows should be as wide as feasible to decrease forage density and increase the evaporative surface.

Harvest Losses

There are a number of losses associated with the production of dry hay (less than 20% moisture). Because the leaves contain about half of the dry matter and two-thirds of the protein, leaf loss has significant impacts on yield and quality.

Respiration

Even after cutting, forages continue to respire and consume sugars until the moisture content drops below 40%. Under relatively fast drying conditions, these losses can be kept to a minimum: 2%–8% of total dry matter. Under poor drying conditions (low temperature, high humidity, etc.), the plants take longer to dry down to 40% moisture and dry matter losses as high as 16% have been measured.

Weathering

Rainfall on windrowed hay sustains respiration and causes other losses. Nutrients such as the simple sugars are leached from the leaves, and leaf loss increases. Digestibility is then decreased. Because sugars are leached from the leaves, which results in less dilution, the percentage of protein increases. However, the amount of protein produced per acre is reduced and protein digestibility also decreases. Weathering also decreases the amount of hay the animals will eat.

Table 5–12.
Potential Haymaking Losses

Source of Loss	% Loss of Dry Matter
Respiration	2–16
Cut and condition	2–5
Rake	5–25
Bailing small bales	3–8
Bailing large bales	1–15
Transport	1–10
Potential total loss	10–71

Mechanical Losses

As forages cure, the leaves and small stems become more brittle. Any mechanical operation, such as raking or tedding, done on material having less than 40% moisture causes leaf losses. The lower the moisture percentage, the greater the losses. Rake when hay is moist. Raking lower moisture hay in the morning with the dew still on will reduce leaf losses. Tedders are more commonly used on grass hay crops. Losses at the baler pick-up and in the baling chamber can be reduced by raking light windrows together at higher moisture and by travelling at maximum ground speed.

Potential Hay Harvesting Losses

The losses from haymaking that have been reported in research trials are summarized in Table 5–12, *Potential Haymaking Losses*, above.

Storage Losses

Hay that is sufficiently dry and is stored under cover will normally experience minimal storage losses. These losses can normally be attributed to handling losses as the bales are moved.

Hay having high moisture is at risk from spoilage due to the action of microorganisms metabolizing sugars in the hay and giving off heat. The final temperature reached by the hay is related to:

- percentage of moisture in the hay
- density of the bale and how tightly bales are packed in the mow
- temperature and humidity of the outside air

Dry hay storage moistures guidelines for various bale types are outlined in Table 5–13, *Storage Moisture Guidelines*, right.

Table 5–13.
Storage Moisture Guidelines

Bale Type	Storage Moisture (%)
Small square bales	15–18
Large round bales – soft core	13–16
Large round-bales – hard core	12–15
Large square bales	12–15

Source: Clarke and Stone, OMAFRA, 1993.

Storing bales inside or covering large bales dramatically reduces spoilage losses. In a 1.5-m (5-ft) round bale, 19% of the hay is in the outside 15 cm (6 in.), and 36% in the outside 30 cm (12 in.). Outside storage should be on a well-drained site. Refer to the OMAFRA Factsheet *Big Bale Hay Storage*, Order No. 88-052, or visit the Web site at www.gov.on.ca/OMAFRA/english/crops.

Hay Heating

The process of wet hay heating up and then burning is typically called spontaneous combustion. Spontaneous heating and combustion occurs when sufficient moisture, oxygen and organic matter are present together to support the growth of bacteria and moulds. The reaction can be self-sustaining. The gases produced will ignite if they have reached a high enough temperature. Care must be taken to ensure that hay is dry enough to be baled and stored. Spontaneous combustion for hay usually occurs within the first 2 months of storage.

Usually, the first indication that the hay may be hot is the release of an odour similar to pipe tobacco and possibly steam rising from the mow. Mow temperatures can be monitored by pushing a pointed probe, constructed of copper tubing, into the hay and then lowering a candy thermometer into it on a string. Never take temperatures alone, because fire pockets can develop, and there is a risk of falling in.

The following temperature guidelines can be used:

- 65°C — Entering the danger zone. Take temperatures daily.
- 70°C — **Danger!** Inspect every 4 hours to see if the temperature is rising.
- 80°C — Fire pockets may be anticipated. **Call the fire department.**
- 100°C — **Critical!** In the presence of oxygen, ignition will take place.

If a thermometer is not available, an iron or copper rod pushed deep into the hay for about an hour will give an indication of the hay's temperature. If it is almost too hot to hold onto with bare hands once it is removed, there is a problem.

Refer to the OMAFRA Factsheet *Silo and Hay Mow Fires on Your Farm*, Order No. 93-025, or visit the Web site at www.gov.on.ca/OMAFRA/english/crops.

Hay Additives

The weather in Ontario often makes it difficult to field-cure dry hay on a consistent basis. Drying agents and hay preservatives are available that can help reduce the dry matter losses associated with making dry hay. They allow for baling at higher moisture or increase the rate of drying.

Hay Preservatives

Since the moisture content at baling determines the amount of preservative, it is important that moisture content be measured accurately. This is probably the weakest link in hay preservation. Moisture testers may not be accurate enough to fine tune the amount of preservative needed. Even if an accurate method such as oven drying of a sample is used, there can be as much as 10%–15% moisture difference within a swath. This variation can lead to pockets of wet material that will be inadequately treated. To determine the range in moisture content, make a few bales and take samples from them rather than the swath.

There is a difference between average moisture content and maximum moisture content. When reading the labels of the various products, pay attention to the wording. Adjust the rate to maximum rather than average moisture content.

There are a number of preservative products on the market that fall into one of three categories:

1. Organic Acids

Mixtures of propionic plus other organic acids when used at the right concentration will allow safe baling at higher moisture without heating damage. The buffered mixtures have a pH of approximately 6.0 and do not remove paint nor irritate the skin and eyes as the older products did. Be sure to observe concentration rates and follow labelled application rates.

These propionic-based products can be successfully used if the following are observed:

- Use the correct rate, which is determined by the moisture content of the hay.
- Determine the application rate based on bale density and moisture tester accuracy.
- Do not mix treated and untreated bales in the mow, because the moisture could migrate from the treated to the untreated and result in spoilage.

2. Anhydrous Ammonia

Anhydrous ammonia is a preservative that will increase the crude protein content and digestibility of poor quality hay. The recommended rate of application is 1% of dry hay weight, and the hay must be no wetter than 30% moisture. The hay should be covered with plastic to retain the ammonia, otherwise the preservative effect is only temporary.

As a preservative, anhydrous ammonia is not as good as the organic acids and should not be used on high-quality hay. **Its use on high-quality hay has caused "crazy cow" syndrome wherein animals run wildly into obstacles, go into convulsions and possibly die.** High-quality ammoniated hay should not be fed to animals with a high nutritional demand such as lactating cows.

3. Bacterial Inoculants

There is limited evidence that hay inoculants containing various bacteria species may reduce heating in baled hay and result in greener colour and less dust. Ask company representatives to provide independent research that substantiates their claims for the product. It is important that the product is labelled for the crop being treated. When using these products, pay careful attention to the recommended maximum moisture levels.

Silage-type inoculants containing *Lactobacillus* species are not effective on dry hay, because there is not enough moisture in hay to support *Lactobacillus* growth. Nor do they function effectively in the presence of oxygen.

Drying Agents

Drying agents such as sodium and potassium carbonates are applied at the time of cutting and can reduce drying time up to a full day under ideal conditions. These chemicals disrupt the waxy layer on the stem which, under good drying conditions, increases the rate at which moisture can leave the plant. To get satisfactory results, the following rules should be observed:

- Apply to stands that are mainly legumes because they do not work on grasses.
- Use a minimum of 334 L water/ha to get good coverage of the cut forage.
- Lay the crop in a wide windrow, to expose as much of the hay as possible to the sun and drying winds.

Even with drying agents, the drying process is still dependent on the weather, requiring high temperatures and low humidity. This makes these agents less effective on the first cut than on the aftermath. In addition, treated windrows do not shed rainfall as well as untreated ones and are more susceptible to rain damage.

Barn Hay Dryers

Barn hay drying systems are installed as a component in the production of quality hay. A properly managed hay drying system reduces field curing time and thus lessens the risk of losses due to rain, minimizes leaf loss and eliminates the danger of fire due to spontaneous combustion (see the section *Hay Heating*, on page 154). A barn hay dryer makes use of a fan-and-air-duct distribution system to force outside air through partially dried hay, placed in storage. This movement of air through the hay removes heat and excess moisture and will eventually complete the drying process that started in the field.

Horse Hay

The quality parameters for horse hay are different than for hay produced for cattle and sheep. Many horse owners judge the quality of hay primarily by its freedom from mould, dust and weeds, and a green colour. Hay that is not adequately dry at baling will mould, which results in dusty hay that causes respiratory problems. Horse hay should not have been rained upon. Many horses do not require hay with a high protein content. A timothy-alfalfa mix is common. Horse hay can often be harvested later in the haying season when the plants are more mature, giving some flexibility in haying and less chance of being rained upon. This will result in a higher yield of dry matter, but the hay will be lower in protein and energy.

There is often a market for horse hay in small square bales, as most horse owners do not have the equipment to handle large bales. Refer to the OMAFRA Factsheet *Hay for Horses* on the Web site at www.gov.on.ca/OMAFRA/english/livestock/.

Haylage and Corn Silage

Storing forage as hay-crop silage, or haylage, has advantages over storing it as hay. These advantages include:

- lower harvest losses
- lower labour costs because all operations can be mechanized
- less dependence on good drying conditions, which allows the crop to be cut at the desired maturity.

Corn silage is a popular forage crop due to palatability, high-energy density and single harvest convenience.

Silage Crop Storage Types

The most common types of silage storage are:

- vertical (tower) silos
- conventional open top
- oxygen limiting (sealed)
- horizontal silos
- bunker
- piles
- silage bags
- large bale haylage

When to Harvest Corn Silage

Harvesting corn silage at the correct moisture is critical for feed quality. The best livestock performance and corn silage fermentation usually occur when whole plant moisture is 65%–70%. This corresponds well to horizontal and bag silos, but silage may have to be somewhat drier in tall tower silos to prevent seepage. Refer to the recommended moistures below.

Kernel Milk Line

The kernel "milk line" is often used to determine when to harvest corn silage. This is done by breaking a cob in half and looking at the kernels. After denting (0% milk line), a whitish line can be seen on the kernels. This line is where the solid and liquid parts of the kernel are separated while maturing and drying. This line will progress from the tip to the base. When it reaches the base (100% milk line), a black layer will occur. The traditional recommendation has been to harvest from one-half to two-thirds milk line.

There is considerable variation in the percentage kernel milk line and the moisture percentage of the whole plant. Whole plant moisture at one-half milk line has a wide range in percentage moistures that may be too wet for some and much too dry for others. When the weather is relatively dry, the whole plant moisture may be lower than expected at any given milk line position. There are also hybrid differences in kernel milk line, due to the "stay-green" characteristic. A high stay-green rating means there is faster grain dry-down relative to stover dry-down. This is desirable in a grain hybrid, because as the grain dries, the stalk stays green and healthy, and broken stalks and lodging in late season are less likely. Many silage-only hybrids have a low stay-green rating, so the grain will have higher moisture relative to the whole plant. Lodging is less important in silage and having more moisture in the grain portion increases starch digestibility. Hybrids with high stay-green ratings may have milk lines that are more advanced relative to whole plant moistures. Silage-only hybrids that have lower stay-green ratings will be ready to harvest at a less advanced milk line. Check with your seed company representative for historic milk line recommendations for a given hybrid.

Measure Percent Moisture

Because of the variation between milk line and whole plant percent moisture, the most accurate method of determining when to harvest is to measure the moisture content. Sample at least 10 plants from the field, avoiding the headlands. Watch for moisture variability within fields. Chop a sample using a harvester or yard chipper. Use a commercial forage moisture tester, microwave or laboratory to determine the percentage of dry matter. Moisture testers and microwaves may not remove all the residual moisture in the sample and may underestimate moisture by about 3%. The finer the sample is chopped, the easier it will be to dry and the more accurate the result.

Shortly after denting, when the milk line is about 20%, a whole plant moisture can be determined. In a typical year, corn silage at this stage dries approximately 0.5% per day. Therefore if the sample was 70% moisture, and 65% moisture is the target, harvest should be done about 10 days after the corn was sampled. In dry years, the drying rate will be more rapid; in wetter years, the drying rate will be slower. Moistures can be checked again closer to harvest if necessary.

Silage Fermentation

When forage is first put into a silo, conditions are aerobic (oxygen is present in the silage mass). Aerobic bacteria produce some heat as they break down carbohydrates and sugars into carbon dioxide and water and use up the trapped oxygen.

When the oxygen has been consumed, the silage becomes anaerobic, which promotes the growth of anaerobic bacteria. These organisms convert the carbohydrates and sugars to organic acids that preserve the silage. In addition, some of the protein is broken down into amino acids, ammonia and other non-protein nitrogen compounds. During this ensiling process, the acids lower the pH, while the production of ammonia tends to raise it. The production of ammonia increases the amount of time it takes to reach a stable pH.

In 2 or 3 weeks, the silage reaches a stable pH of 4.0 to 5.0, and all bacterial and enzymatic activity stops. Once this stable pH has been reached, further breakdown of nutrients and spoilage is prevented, and the silage will keep for extended periods of time, provided air is excluded.

Silage Storage Losses

Most silage storage losses are associated with exposure to oxygen.

Respiration Losses

When plants are harvested and ensiled, the plant cell respiration continues, resulting in a breakdown of sugars and other carbohydrates.

Fermentation Losses

Primary and secondary fermentation result in varying amounts of fermentation losses. An extended period of fermentation can result in an excessive breakdown of sugars. Some types of bacteria are less efficient than others. At moistures over 70%, a clostridia fermentation can occur, which is very inefficient and produces high levels of butyric acid.

Seepage Losses

When excessively wet material is put into a silo, the weight of the material can squeeze moisture from the silage at the bottom. The seepage carries sugars and other nutrients out of the silo. In addition, seepage can lead to excessive corrosion of the silo walls, reinforcing rods and the possible collapse of the silo. Silo seepage is also harmful to the environment. Refer to the OMAFRA Factsheet *How to Handle Seepage From Farm Silos*, Order No. 95-043, or visit the Web site at www.gov.on.ca/OMAFRA/english/crops.

Heating

Heating causes plant sugars and proteins to combine and form indigestible compounds. This results in a "toasting" or browning of the silage and reduced protein digestibility. In extreme cases, because the silage is too dry or a continuous supply of air is getting into the silage, spontaneous combustion can lead to a fire. Such fires can happen at any time of the year and are almost impossible to extinguish.

Surface Spoilage

Less compacted, uncovered silage spoils because continuous exposure to oxygen results in the growth of aerobic microorganisms (yeast, moulds and aerobic bacteria).

Feed-Out Losses

When a silo is opened to remove feed, there can be further losses in feed value. These losses are caused by moulds and yeast that become active in the silage when it is again exposed to oxygen. Secondary losses can occur at the cut face of the silage mass or in the bunk while being fed.

Recommended Haylage and Corn Silage Management Practices

1. Store at Correct Moisture Content

- conventional upright silos: 60%–65%
- horizontal silos: 60%–70%
- oxygen-limiting silos: 50%–60%
- bag silos: 60%–70%
- wrapped large bale haylage: 40%–60%.

Silage that is too dry will result in poor packing and air exclusion, poor fermentation and the production of heat. If haylage becomes too dry, cut fresh material and continue to fill the silo by alternating fresh and dry loads. The addition of water will not increase the moisture of dry silage. The water is not absorbed by the silage and can easily run off; a garden hose does not deliver enough water to make an appreciable difference in moisture content. Silage harvested at moisture percentages greater than 70% can result in seepage and an undesirable clostridia fermentation that results in butyric acid formation, high dry matter losses and poor feed quality, palatability and intake potential.

2. Use Proper Length of Cut

Fine chopping helps to exclude air by allowing tighter packing but needs to be compromised with rumen function requirements. The actual particle length will be different from the theoretical length of cut (TLC) and can be checked with a particle length separator.

With haylage, a 10-mm ($^{7}/_{16}$-in.) TLC is usually desirable. Low moisture silage may require a shorter TLC (6 mm or $^{1}/_{4}$ in.) to ensure adequate packing. The length of cut is probably more critical with horizontal silos, although it is still important with upright and sealed silos. Harvester blades must be sharp and correctly set. Chopping finer than 6 mm ($^{1}/_{4}$ in.) is not recommended as it doesn't improve packing but does require more horsepower and may result in nutritional problems.

Corn silage harvest processors use rollers attached to the chopper to break cobs, crack kernels and shred stalks. The TLC recommended with processors is 19 mm ($^{3}/_{4}$ in.) rather than 10 mm ($^{7}/_{16}$ in.) without a processor. Processors may be more beneficial with relatively dry, hard-kernel, textured corn.

3. Fill Silos Rapidly

Fill as quickly as possible to speed fermentation and minimize spoilage. If filling is delayed for a few days, the silage should be covered with plastic to reduce the chance of spoilage. In an upright silo, the silage is not compacted until a considerable depth of material has been put in the silo. The top part of the silage will be less dense and hold more air that could cause heating and loss of quality.

4. Pack Horizontal Silos Well

Bunk silos should be filled from back to front so that a "progressive wedge" shape is created, rather than filling from bottom to top. As the silo is filled, it should be packed in relatively thin layers (15 cm or 6 in.) to obtain good air exclusion. Sufficient tractor weight and packing time are critical. This may mean adding more packing tractors or reducing the delivery rate of silage to the bunker to increase packing time per tonne.

5. Provide a Tight Tower Silo

A tower silo can act as a chimney. If air can get in, it will move up through the silage mass, which could lead to spoilage, heating of the silage and, in extreme cases, fire. Cracks in the silo walls or around the doors should be caulked or reconditioned to prevent the entry of air.

6. Distribute Silage Evenly Within Tower Silos

Without good distribution, the lighter material will collect along the wall, thereby leading to poor packing.

7. Seal Silos Well

- Covering and sealing with plastic is essential in horizontal silos. The plastic should be held firmly in place. Old tires placed closely together (touching) work very well. The plastic should not be allowed to flap in the wind, because it then acts as a bellows and pumps air into the silage rather than excluding it.
- In conventional tower silos, forage at the top has low density that air can penetrate. To reduce spoilage until fermentation is complete, silage should be covered with plastic and weighted down by a few centimetres of silage. Take silo gas precautions. (See the section *Silo Gas*, on page 159.)
- In sealed silos, the hatches should be closed at night and during interruptions in filling. When filling is complete, the hatches should be closed immediately.

8. Allow Complete Fermentation

Silage fermentation requires up to 21 days. To ensure silage stability and maximize feed bunk life, do not feed out of the silo until this is complete.

9. Feed Out Quickly to Minimize Spoilage

The removal rate will determine the amount of spoilage at the face of the silage. Silos should be sized accordingly. Tower silos should be emptied at a rate of at least 5 cm (2 in.) per day in winter and 7–10 cm (2¾–4 in.) per day in summer. Horizontal silos should be fed out at a minimum rate of 10–15 cm (4–6 in.) per day, depending on the season.

10. Silage Face Management to Minimize Spoilage
Silage should be removed from horizontal silos by scraping the silage face from top to bottom with the loader bucket. Removing silage by lifting the bucket from the bottom to the top disrupts the pile and allows oxygen to penetrate and initiate aerobic spoilage. Shear buckets that minimize silo face spoilage are also commercially available.

Silage Bacterial Inoculants

Silage inoculants are additives containing lactic acid bacteria (LAB) that can enhance fermentation. The LAB increases the rate and efficiency of fermentation, causing the pH to decline faster. The primary benefit is decreased dry matter losses. Protein solubilization can be reduced slightly. Animal performance and feed efficiency can be improved. Bunk life may or may not be improved, depending on the pH and acetic acid levels.

Bacterial silage inoculants usually contain *Lactobacillus plantarum* and other bacteria species. The product should supply at least 100,000 live bacteria cfus (colony-forming units) per gram of forage when applied at the recommended rates. Liquid products may have some advantage over dry products because of more uniform application.

If there is a high natural population of lactic acid bacteria, an inoculant is less likely to provide a benefit. The natural population is increased by higher than average wilting temperatures, longer wilting times, rain during wilting and higher moisture contents during chopping. Inoculants are usually less beneficial in corn silage than in haylage.

The application of a silage inoculant will not overcome the effects of poor silage management or poor weather conditions. These products are most effective when applied to top quality forage under top management.

Forage additives, including silage inoculants, must be registered with the Canadian Food Inspection Agency (CFIA) to be sold in Canada. To receive a "permanent" registration, companies must provide research that substantiates a nutritional label claim. Where research has been conducted but the results are not conclusive, products may be eligible to receive a "temporary" registration for up to 3 years to conduct additional research that substantiates a label claim. Temporary registration numbers start with a "T." Ask company representatives to provide independent research that substantiates their claims for the product. It is important that the product is labelled for the crop being ensiled, and that directions for storage and use are followed.

Table 5-14.
Common Silage Problems and Causes

Problem	**Causes**
Hot or mouldy silage	• Low moisture content • Slow silo filling • Air leaks • Poor compaction • Slow feed-out
Caramelized (dark, tobacco smell)	• Heat damage caused by low moisture or poor compaction
Frozen silage	• Moisture too high • Poor fermentation
Vinegar odour	• Excess acetic acid caused by low plant sugars or poor fermentation
Seepage	• Moisture too high
Rancid odour	• Butyric acid from clostridia fermentation caused by too high moisture
Alcohol odour	• Yeast fermentation from slow feed-out, oxygen or low lactic acid bacteria

Common Silage Problems and Causes

There are several common problems associated with silage. Table 5-14, *Common Silage Problems and Causes*, above, lists potential reasons for these problems.

Silo Gas

Nitrogen dioxide, NO_2, is a dangerous chemical asphyxiant that is produced as a result of chemical reactions that take place almost immediately after plant material is placed into a silo. Even short-term human exposure can result in sudden death. It has a characteristic bleach-like odour and may be visible as a reddish-brown haze. It is heavier than air, therefore it will tend to be located just above the silage surface. It may also flow down silo chutes and into feed rooms.

Weather conditions and cultural practices will affect the amount of nitrates in plant material, which in turn will set the stage for the production of NO_2 in the silo. For example, a dry period during the growing season followed by abundant rainfall will encourage a corn crop to take up high levels of dissolved nitrates. If the corn is harvested before the nitrates can be converted to proteins, nitrous oxide (N_2O) and nitric oxide (NO) are produced. Unstable NO combines with oxygen to form deadly nitrogen dioxide.

When inhaled, NO_2 dissolves in the moisture on the internal lung surface to produce a strong acid called nitric acid. Nitric acid burns the lung tissues, which is followed by massive bleeding and death. Repeated exposure to lower concentrations of NO_2 will cause chronic respiratory problems, including shortness of breath, coughing and fluid in the lungs. Seek medical attention immediately.

Silo Gas Precautions and Procedures

- Post a "Silo Gas" warning sign in a visible location near the silo.
- Do not allow children or visitors near the silo for 3 weeks after filling.
- Contact your local fire department to determine if pressure-demand remote breathing apparatus is part of their emergency equipment. SCUBA equipment is not suitable because the air tank is too big for climbing the silo chute or the outside ladder-cage.
- Provide sufficient feed room ventilation to exhaust any silo gas that may have spilled from the silo.
- During filling, adjust the distributor as needed to level silage. Do not level material by hand.
- If it is necessary to enter the silo when filling is complete, do so immediately following the last load, on the same day. Leave the blower running while inside the silo.
- Silo entry should not be attempted without wearing a lifeline that is in the hands of sufficient outside help to pull you to safety.
- If it becomes necessary to enter an oxygen-limiting silo, it is essential that an external air supply be worn.
- A top unloader can usually ventilate a silo effectively. However, if it becomes necessary to service a defective unloader, assume that gases are present. To expel gases before entering, run the forage blower with the chute doors closed and the roof vent open. If the head space is greater than 5 m (16 ft), attach a tube adapter to the blower pipe. For a 7.2-m (24-ft) diameter silo with 5–10 m (16–33 ft) of head space, increase the ventilation time. Leave the forage blower running while in the silo.

Refer to the OMAFRA Factsheet *Hazardous Gases*, Order No. 99-001, or visit the Web site at www.gov.on.ca/OMAFRA/english/crops.

Large-Bale Haylage

Large-bale haylage, or "baleage" as it is also called, has become popular as an option for storing excellent-quality forage. By making large bales into haylage, a farmer can be more aggressive and consistent in cutting schedules as it reduces the weather risk factor. Some farmers use this as their main storage system, but it is more commonly a flexible second system of storage when silos are full and the weather doesn't permit drying. It produces a long stem haylage. Plastic bagging or plastic wrapping is used.

The system makes use of equipment such as large round balers, which are readily available. Baleage may be fed using the same equipment as dry, large bales. This provides flexibility, to make as little or as much large bale silage as the weather dictates. Heavier equipment and four-wheel-drive tractors may be required when handling the heavier bales.

The cost and disposal of the plastic coverings have been major concerns. Cost is rationalized by considering the higher protein and energy value of the stored forage and the importance of the storage itself. Reduced harvesting losses and the higher quality of the whole forage crop as the harvest is moved ahead should be considered when determining the cost benefit of the system. Refer to the OMAFRA Factsheet *Recycling Farm Plastic Films*, Order No. 95-019, or visit the Web site at www.gov.on.ca/OMAFRA/english/crops.

With large-bale haylage, there is less or incomplete fermentation resulting in a higher pH, or less acidic environment, and a more unstable silage than conventional haylage. This means that greater emphasis must be put on good silage-making processes, especially the exclusion of oxygen. The length of storage time and how long the bales are exposed to oxygen before feed-out must be adjusted to weather conditions.

Successful use of baleage involves the following management practices:

- Bale a good quality forage within 40%–60% moisture content in a very compact, even bale.
- Avoid contamination by manure use and soil-borne bacteria splashed up with rains or by raking.
- Store the bales quickly, excluding the oxygen as soon as possible. Monitor bales to maintain a continuous seal.
- Ensure efficient, quick feed-out to avoid bunk spoilage.
- Use good-quality plastic to produce a sealed environment.

Weed Control

Critical Period for Weed Control

There are no critical periods established for forage crops. When establishing forages, it is very important to control weeds early in the growth of the forage crop. The product label for postemergence herbicides indicates the growth stage of the weeds when optimum control can be obtained. Young forage legumes are very sensitive to herbicides, and the correct rate and crop growth stage are essential. The timing of weed control should optimize the critical period for the crop and the optimum growth stage of the weed.

In established forages and pastures, most herbicides to control biennial weeds are best applied in early fall to first-year growth or in late spring to second-year growth unless otherwise noted on the label. Mechanical control of biennial broadleaf weeds is most successful when done at the time of flowering. Perennial weeds are usually best controlled when treated the end of May to mid-June when the weeds are actively growing (unless otherwise noted on the label). If you are wick weeding pastures for Canada thistle or milkweed, wait until they are in the bud-to-flowering stage.

Some herbicides prohibit feeding the year of treatment. Consult the label in regard to the period of time to keep grazing livestock out of the treated area or for the period between treatment and harvest of hay or hay silage.

Crop Restrictions

Note that some herbicides used in corn and soybeans can leave soil residues that may injure forage seedlings. Some of these may be dependent on soil pH or organic matter. Consult the label of last year's herbicides to note any restrictions before establishing new seedlings. See the section on "Herbicide Crop Rotation Restrictions" in OMAFRA Publication 75, *Guide to Weed Control*.

Crop Losses Due to Weeds

Yield losses will vary with the species and the density of the weed as well as when the weeds emerge. Later-emerging plants tend to be less competitive and produce fewer seeds per plant. Established forages are more competitive with weeds than newly established forages.

Crop quality should also be a consideration when making weed control decisions. The presence of weeds can reduce the quality and the value of the hay. Some weeds can also reduce the palatability of the hay or forage.

Integrated Weed Management

Crop rotations can be effective in reducing certain perennial weeds that may grow best in a particular crop. Forages are known to reduce the populations of annuals in the first year of the next crop, but annual weeds can be a problem when establishing forages. Use vigorous, high-quality seed to achieve uniform stands at the recommended plant populations to compete with the weeds. Early planting gives the crop a head start on the weeds to assist with crop competition. Planting deep will delay emergence and favour the weeds.

Equipment can tend to move weed seeds from field to field. Harvesting equipment, tillage equipment and soil erosion can all transport weeds. Weeds can also infest a field from manure or other soil amendments. Proper sanitation and cleaning of equipment along with maintenance of field border areas all affect the long-term weed management in the field.

Refer to OMAFRA Publication 75, *Guide to Weed Control*, for more information, including herbicide products and rates.

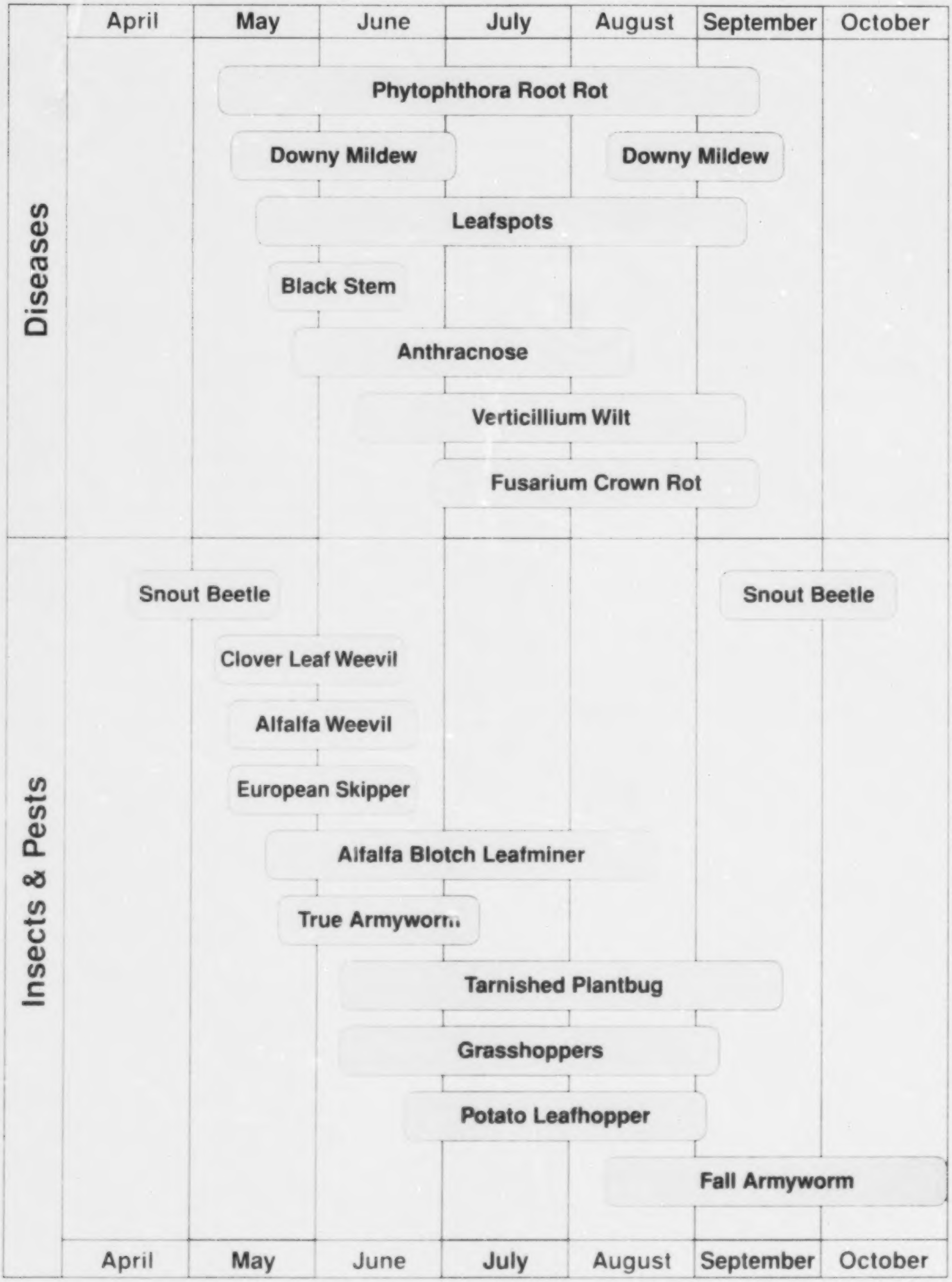

FIGURE 5–3
Forages Scouting Calendar

Insects

Table 5–15, *Symptoms in the Field*, below, shows insects and pests that could be causing the symptoms in the field.

Individual descriptions of insects and diseases found in forages and recommendations for their control follow.

Table 5–15.
Symptoms in the Field

	Possible Insect Source						
Symptom	**Alfalfa blotch leafminer**	**Alfalfa snout beetle**	**Alfalfa weevil**	**True Armyworm**	**Fall Armyworm**	**Grasshoppers**	**Potato leafhopper**
Plants Wilting or Dying							
Deep spiral grooves in taproot		x					
Feeding Injury							
Mines or tunnels between top and bottom layers of leaf	x						
Pinholes or skeletonization of leaves			x				
Leaf margin feeding, feeding damage to blossoms				x	x[1]	x	
Leaf Discolouration							
V-shaped yellowing at leaf tip; leaves appear burned							x

[1] Moist red frass present.

Alfalfa Snout Beetle

Description: The adult is a flightless, dark grey weevil approximately 12 mm in length (see Plate 89 on page 290). Larvae are small, white and legless with a light-reddish-brown head and can be found in the soil, feeding on or in the roots (see Plate 90 on page 290).

Life History: The snout beetle has a 2-year cycle. Adults emerge from their overwintering sites in April, feed on new alfalfa shoots and migrate into new fields to lay eggs. Adults may walk short distances or may be carried longer distances via the transportation of soil, gravel, hay, farm machinery and waterways. All the adults are female. The eggs soon hatch and begin feeding on the main and side roots of the host plant. The total life cycle requires a span of 2 years.

Damage: This potentially serious pest of forage crops was discovered in Eastern Ontario near Prescott and Brockville. The larvae girdle the taproot or gouge its surface leaving deep spiral grooves. Severely injured plants may appear yellow and leafless in the fall. Adults feed on leaves and stems causing only marginal damage. Damage is most evident in late summer and early fall.

Scouting Technique: Early-season scouting for beetle migration should be done in infested counties of Eastern Ontario. Later in the season, wilted plants should be dug and checked for damage and the presence of larvae. Alfalfa snout beetle has a wide range of hosts. Although it finds alfalfa to be the most attractive crop, larvae of the insect may attack all species of clover, grape and strawberry. They sometimes even feed on weeds, especially ones with fleshy roots such as wild carrot and dandelion.

Action Thresholds: None available.

Management Strategies: Rotation of alfalfa with non-host crops breaks the cycle and decreases the population of snout beetle significantly. Non-host crops include corn, small grain cereals and soybeans. In heavily infested fields, it is recommended that the rotation crops be grown for at least 2 years to reduce the insect population dramatically.

To minimize the chance of transporting this pest, all farm machinery should be cleaned thoroughly before being moved from an infested field. First-cut hay from infested fields should be stored for at least 2 months before it is shipped. There are restrictions on the transportation of hay, straw, soil and compost material from infested fields. If you suspect you have this pest, consult the provincial field crop entomologist or forage specialist.

Alfalfa Blotch Leafminer

Description: The adult is a very small, black, hump-backed fly. The larvae are small, pale yellow maggots found within tunnels in the leaf tissue.

Life History: In late May, the adult fly emerges from pupa overwintering on the soil surface. The female adult lays her eggs inside the leaves of new alfalfa plants. The larvae develop inside small tunnels in the leaves. Mature larvae drop to the ground when mature and pupate. A second generation of adults appear in approximately 1 week (mid-July) and a third generation appears in mid-August.

Damage: This pest of alfalfa is now a more serious problem in Northern Ontario. Small pinhole punctures are left in the leaves when the adult feeds and lays its eggs. The developing maggots feed inside the leaflet, creating tunnels or mines between the top and bottom layers of the leaf. These tunnels usually begin at the base of the leaflet and widen towards the leaf apex, creating a "blotch" appearance (see Plate 91 on page 290). Feeding damage primarily decreases forage quality and seldom causes yield loss.

Scouting Technique: Scout fields weekly to determine the percentage of leaves with pinhole feeding.

Action Thresholds: Control is only necessary if more than 40% of leaflets show adult pinhole feeding.

Management Strategies: A species of parasite successfully controls the alfalfa blotch leafminer in Southern Ontario. Insecticides are harmful to this parasite and, therefore, are not recommended unless leafminer populations are extremely high. Refer to the OMAFRA Publication 812, *Field Crop Protection Guide*, for recommended insecticide products. For insecticides to be effective, they should be applied no later than the pinhole stage of feeding.

Alfalfa Weevil

Description: The adult weevil is a brown snout beetle, about 5 mm long, with a dark brown stripe extending from the head down the centre of the back (see Plate 92 on page 290). Larvae are bright green with a black head, six legs and a distinctive white stripe down the centre of the back. At full size, they are about 8 mm long (see Plate 93 on page 290).

Do not confuse the alfalfa weevil larvae with the clover leaf weevil larvae, which are larger, have a light brown head instead of a black head and a white stripe edged with pink. Also, do not confuse alfalfa weevil larvae with predacious fly larvae, which have no head capsule and are legless.

Life History: Adults overwinter in plant debris and emerge in spring to feed on new alfalfa growth and lay their eggs in alfalfa stems in May. Larvae hatch from eggs and crawl to the tops of alfalfa where they feed on the developing leaf and flower buds. After feeding, larvae form loosely woven white cocoons in leaf masses and enter the pupa stage, usually in late June or early July. Pupa hatch in 1 or 2 weeks into the adult stage.

Damage: The larvae cause most of the damage as they feed within the leaf buds and then move to the tips of the plant. Damage starts out as pinholes and progresses to feeding between the leaf veins, resulting in a skeletonized appearance. In heavy infestations, larvae shred the leaves so badly that fields take on a greyish-white or frosted appearance. Adult feeding throughout the summer does not cause significant damage.

Scouting Technique: Examine each field twice a week from mid-May to June. Check several areas throughout the field. Look for damage to show up first on shallow soils or on southerly slopes, particularly during warm, dry springs. Experience in Ontario has shown that the peak of larval attack usually coincides with the bud stage of the first crop. To count larvae, collect 30 stems in an M-shaped pattern. Place them inside a white pail and beat them against the side to knock off the third-to-fourth-stage instar larvae. First and second instars are smaller (3 mm or less), pale yellow-to-light green, with the white stripe not yet distinguishable. They may be in the upper leaves but do not include these younger larvae in the count. Check to see whether the weevil larvae look active and healthy. Larvae infected by the fungus pathogen are slow-moving, yellow or tan larvae.

Action Threshold: Leaf tip damage and weevil counts are used in assessing threshold levels and appropriate action of either cutting or insecticide application. **If there is 40% leaf tip feeding, with two or three active weevils per stem, and there is more than 7–10 days to the preferred harvest date, consider applying an insecticide.** Leaf tip feeding refers to the percentage of plant tips showing obvious signs of damage, which is not to be confused with the percent defoliation.

- Less than one active larva per stem does not require action, however, continue to monitor the situation.
- If the alfalfa is less than 30 cm (12 in.) high with more than one larva per stem, action is required.
- Two larvae per stem requires action if the alfalfa is less than 40 cm (16 in.) high.
- If there are more than three active larvae, immediate action is required.

Occasionally, if weevil populations are high on a late first cut, surviving larvae will feed on the regrowth. Such feeding can eliminate alfalfa regrowth which may lead to a loss of the stand. With a severe infestation, be sure to monitor stubble regrowth. The characteristic symptom is the alfalfa plant not "greening up" due to weevils feeding on the developing crown buds. **The presence of two or more active larvae per crown, or 4–8 larvae/ft^2 indicates a need to spray the stubble with insecticide.**

Management Strategies: Fungal disease and several species of parasites have been established in Ontario and in most years, forages stands do not warrant treatment with insecticides. The key to weevil control is proper timing of harvest or insecticide application based on field inspection. When threatening infestations occur, fields should be cut immediately to eliminate feeding damage. The bud stage is also the best time to cut the crop for maximum quality. Occasionally, warm May weather will result in an early hatch of weevil and feeding damage will show before it is practical to harvest the alfalfa. In those situations, an insecticide may be warranted. Refer to OMAFRA Publication 812, *Field Crop Protection Guide,* for insecticide information. Insecticides for alfalfa weevil may also control other pests such as potato leafhopper and lygus bug. However, it should be noted that spraying insecticides on alfalfa will also kill beneficial insects, the natural enemies of these pests. This increases the potential for future outbreaks of these pests.

Potato Leafhopper

Description: The potato leafhopper (PLH) adult is a pale green, wedge-shaped, winged insect about 3 mm long with piercing and sucking mouthparts (see Plate 56 on page 283). It is most broad towards the head, tapering evenly to the wing tips. It has a row of six rounded, white spots behind the head. Nymphs are smaller than adults are and wingless.

Life History: PLH do not overwinter in Ontario, but migrate north every spring, carried by southerly, low weather fronts that start in the Gulf of Mexico. Adults may arrive in late spring and begin sucking on plant juices. Females lay their eggs in the tissue of main veins and petioles of leaves. Development from egg to adult takes approximately 4 weeks.

Damage: Damage is most severe in new seedlings and in young regrowth. While potato leafhopper nymphs and adults suck juices from plant foliage, they inject a protein that blocks veins. This causes the edges to become yellow and puckered, with a characteristic yellow "V" shape beginning at the tip of the leaves. When severe, the leaves appear burned, which is called "hopperburn" (see Plate 94 on page 290). PLH can cause a 2%–3% reduction in the percentage of protein, in addition to reducing both the average height and yield. Border areas are usually affected first. Leafhoppers tend to come into soybean and edible bean fields after neighbouring alfalfa fields are cut. The symptoms of potato leafhopper are commonly confused with herbicide injury problems and nutrient deficiency. Most of the damage occurs from June to mid-August. High risk factors include hot, drier-than-normal seasons.

Scouting Technique: Take 20 sweeps from five areas of the field beginning in late June. Avoid field edges. Determine the average number of PLHs per sweep. Next, take 20 alfalfa stems at random and record the average plant height. See the section *Scouting Tools and Techniques,* on page 1, for a discussion of the sweep net method.

Action Thresholds:

Stem Height	Number of PLHs per Sweep
9 cm (3.5 in.)	0.2 adults
15 cm (6 in.)	0.5 adults
25 cm (10 in.)	1.0 adults or nymph
36 cm (14 in.)	2.0 adults or nymph

Management Strategies: Resistant varieties are available that use glandular hairs as the resistance factor. These glandular hairs, both on the leaves and stems, act as mechanical barriers to PLH feeding. Cutting alfalfa early will potentially reduce egg, nymph and adult populations. A naturally occurring fungal pathogen helps reduce the populations of the PLH under cool, moist conditions. Predators and parasites appear to play a minor role in controlling the pest. If populations exceed the action thresholds, an insecticide may be necessary. Refer to OMAFRA Publication 812, *Field Crop Protection Guide,* for insecticide information. It should be noted that spraying insecticides on alfalfa will also kill beneficial insects, the natural enemies of PLH, alfalfa weevil and lygus bug.

European Skipper

Description: The skipper is a sporadic pest of timothy, both in hay and seed production. The adult is a pumpkin-orange butterfly with a 2.5-cm wing spread that skips about hay fields in midsummer. Mature larvae are light green, approximately 2.5 cm in length and have brown heads with two light bands. Younger larvae have black heads that eventually turn brown. Larvae can usually be found within rolled leaves where they feed.

Life History: Eggs overwinter on the stems of crop debris and weeds and hatch in the spring. Young larvae roll themselves up in the leaves and seal the leaves closed with silk webbing. Larvae feed on timothy until late June. The larvae then attach themselves to grass stems or the underside of weed leaves and develop into chrysalids (the pupa stage of the butterfly). In approximately 2 weeks, the adult skipper emerges. There is one generation per year.

Damage: Larval feeding causes leaf margins to become irregularly notched and when abundant can cause defoliation. When the population is very high, the larvae will also feed on the heads of plants, leaving only the stems remaining in a field. Adult skippers feed on the nectar of flowers and weeds and do not cause any damage to plants.

Scouting Technique: Begin scouting for larvae by late April. Remove five random, 1-ft^2 samples of forage down to ground level and place them along with the old crop residue into a bag. Tie the bag and leave overnight at room temperature. The caterpillars will crawl out of the residue and can be counted easily.

Action Threshold: Six larvae in a 30 x 30-cm area found in the early, brown-headed stage.

Management Strategies: Refer to the OMAFRA Publication 812, *Field Crop Protection Guide*, for insecticide recommendations.

Grasshoppers

Description: There are several species of grasshopper that may attack forages. They vary in colour from green to brown. Nymphs look similar to adults but are smaller and have incomplete wings. Both stages feed by chewing. All species have enlarged hind legs for jumping.

Life History: Grasshoppers overwinter as eggs in the soil, usually in uncultivated fields and pastures. Nymphs hatch from the eggs in early June and begin feeding on emerging plants. Nymphal stages last for approximately 2 months with adults appearing later in the season to feed, mate and oviposit their eggs in the soil for next year's population. Grasshoppers prefer to lay eggs in sandy soils with grassy, undisturbed areas. Drought conditions for 1–2 years favour egg and nymph survival.

Damage: Both adults and nymphs feed on the leaves. In alfalfa grown for seed, grasshoppers may become destructive by feeding on blossoms and seed pods. High infestations can defoliate fields and cause yield loss. Feeding damage usually begins around the borders of fields, adjacent to grassy fencerows. High risk factors include no-till, grassy fields, dry, open autumn seasons and mild winters.

Scouting Technique: Begin scouting in late June when grasshoppers are still young. Scout adjacent fencerows and grassy borders.

Action Thresholds: An average population of 15–20 nymphs/m^2 in the spring may warrant control.

Management Strategies: Early-season control should be concentrated on the boundaries of the field in those areas with high nymphal populations. Refer to OMAFRA Publication 812, *Field Crop Protection Guide*, for insecticide recommendations. It should be noted that spraying insecticides on alfalfa will also kill beneficial insects, the natural enemies of potato leafhopper, alfalfa weevil and lygus bug. Several natural enemies, including ground beetles and crickets, feed on the egg stage while birds and spiders feed on the nymph and adult stage, helping to reduce the populations. The fungus *Entomophthora grylli* can reduce the populations when weather conditions are warm and humid. Removal of grassy weeds in fields and borders by tillage helps reduce nymphal numbers that require these plants to survive. Tillage buries eggs deeper in the soil, hindering nymphal emergence. Chemical control is more effective on nymphal stages than adults.

True Armyworm

Description: True armyworms are 4 cm or 1½ in. (full grown), dull green-to-brown larvae that can be easily confused with other caterpillars, including variegated cutworm and fall armyworm. Two distinguishing features that true armyworm possesses are white-bordered stripes running laterally along the body and dark diagonal bands at the top of each abdominal proleg (see Plate 18 on page 277). The head is yellow-brown with a network of dark brown lines creating a pattern.

Life History: In early spring, the moths prefer to lay their eggs in grassy vegetation. Larvae hatch from the eggs and feed at night or on overcast days for approximately a month. There are two generations per year, but it is the first generation that tends to do the most damage in corn in Ontario.

Damage: True armyworm larvae feed at night. Most feeding damage is done on cereals during July. True armyworms do not feed on pure stands of alfalfa but will feed on alfalfa/grass mixtures. The larvae strip the leaf margins, moving up the plant to feed on the panicles and flowers.

Scouting Technique: The best time to scout for true armyworm is early evening, just before sunset. Examine 20 plants from five locations in the field (100 plants in total). During the day, you may find the larvae amongst the crop debris on the soil surface or under soil clods. Also, you may find brown frass, often mistaken for eggs, on the soil near the plant. Record the size and number of larvae. When scouting, check the backs of armyworms for eggs. These small, oval, yellowish eggs are usually located just behind the head of the larva. These are eggs of a parasitic fly. The eggs will hatch, and the maggots will kill the armyworm larvae.

Action Threshold: If 50% of the plants are infested with larvae smaller than 2.5 cm (1 in.), insecticide may be warranted. Avoid treating with insecticides when large numbers of parasitized larvae are present.

Management Strategies: If the larvae are almost full grown (about 4 cm or 1½ in. long), there is no benefit in applying insecticide since most of the feeding damage has already been done. Insecticides will only be effective on larvae that are less than 4 cm or 1½ in. Refer to OMAFRA Publication 812, *Field Crop Protection Guide*, for insecticide recommendations. Treatment may be confined to infested areas. The parasites and other beneficial organisms usually keep armyworms from reaching damaging levels. Avoid treating with insecticides when large numbers of parasitized larvae are present.

Fall Armyworm

Description: Full-grown fall armyworms are 4 cm (1½ in.) long, varying in colour from light tan or green to near black (see Plate 19 on page 277). Three white, thin strips run down the back with one thicker, yellow band with red spots running along the side, just above the legs of the larvae. Scattered along the body are black spots called tubercles that have spines emerging from them. The fall armyworm larvae can be distinguished from the true armyworm by a white inverted "Y" on the front of the head of the fall armyworm. The fall armyworm head is dark brown.

Life History: Fall armyworm adult moths migrate from the southern states and show up later in the season when the corn is fully grown. This insect cannot overwinter in areas where the ground freezes.

Damage: Feeding in forages usually occurs in late summer, early fall. Fall armyworm is an occasional pest of grass crops such as corn and wheat but will also feed on mixed stands of alfalfa and grass. Fall armyworm feeding occurs in the daytime, unlike true armyworm feeding, which occurs at night. Initial leaf feeding appears as ragged-edged holes and moist, reddish-brown frass can be found nearby. Grazed fields will develop browned or burned spots and will appear thinned out due to the armyworm chewing off the new foliage. Where pastures or hayfields have substantial growth accumulation, armyworms can defoliate entire fields, leaving only short, dried-out stems. Newly fall-seeded alfalfa stands are most at risk.

Action Threshold: If 50% of the plants are infested with unparasitized larvae smaller than 2.5 cm (1 in.), insecticide may be warranted.

Management Strategies: For insecticide recommendation, see OMAFRA Publication 812, *Field Crop Protection Guide*. Armyworms tend to move in large numbers from one field to another. When this happens, it is advisable to spray the border of the invaded field. **Chemical control is not effective on larvae greater than 2.5 cm or 1 in.** The parasites and other beneficial organisms usually keep armyworms from reaching damaging levels. Avoid treating with insecticides when large numbers of parasitized larvae are present. Grassy areas in and along the field borders are attractive to the egg-laying moths, therefore, eliminating grasses and weeds from the corn field is recommended. Late-season grass control may not be a good option since this will promote the feeding larvae to migrate from the grassy weeds that are now dead to the crop itself.

Diseases

Verticillium Wilt

Incidence: Verticillium wilt of alfalfa is a disease that increases with stand age, therefore, it mainly occurs after the second year of production. The fungus responsible for this disease can be found in most areas of southern Ontario. Farms with a history of the disease may find dead plants in younger stands (second-year). Verticillium wilt can reduce yields up to 50% and shorten the life of the stand.

Appearance: Initially, a few stems are affected and eventually, the leaves on infected plants wilt, curl inward and become orange-brown or tan-brown (bleached) (see Plate 95 on page 291). In the early stages of disease development, leaves will exhibit a V-shaped yellowing of the leaflet tips. Growth is often considerably stunted, and plants eventually die. Although all the plant leaves may die, the stems remain green. The fungus enters through the root or cut stems and is spread from older infected stands to younger stands by harvest equipment, insects and manure. The disease causes a brown discolouration of the interior root and stem (vascular) tissue. Cutting the stem in half will usually reveal this browning.

Disease Cycle: The *Verticillium* fungus enters the plant primarily through the roots. The fungus blocks or inhibits the plants' ability to move water, resulting in wilting. The fungus survives (overwinters) in infected plant debris. During cool, moist conditions, numerous spores are produced on diseased tissue.

Management Strategies: The disease is best managed by the use of varieties rated as resistant and highly resistant. For variety ratings for Verticillium wilt, consult the current edition of the report, *Ontario Forage Crop Variety Performance*, available at your local OMAFRA Resource Centre and online at www.plant.uoguelph.ca/performance_recommendations/ofcc/ofcc.htm. Treating seed with a fungicide will help reduce early infection. For fungicide recommendations, refer to OMAFRA Publication 812, *Field Crop Protection Guide*. The fungus is spread primarily on the cutting bar of forage harvesting equipment. Before harvesting, clean the cutting bar with a 1% solution of bleach followed by a clean water rinse and oil spray. Cut the youngest non-infested fields first, working towards the oldest fields. Early harvest can limit yield and quality losses and slow fungus spread from field to field. Wait 2–3 years between alfalfa crops. Maintain a good weed control program, since some weeds can be alternate hosts. For additional information, see the OMAFRA Factsheet, *Verticillium Wilt of Alfalfa*, Order No. 88-036, or visit the Web site at www.gov.on.ca/OMAFRA/english/crops.

Phytophthora Root Rot

Incidence: Phytophthora root rot is an important and common disease of alfalfa. The disease shows up in Ontario mainly on poorly drained soils or on clay loam soils during extended periods of wet weather.

Appearance: Infection occurs as plants emerge. Therefore new seedlings are most at risk. As the stand gets older, the risk declines somewhat. Infected seedlings are stunted, grow slowly due to a reduced root system and eventually begin to wilt (see Plate 96 on page 291). A girdling, pinching or damping-off of the stem, at the soil line, may be seen causing the seedling to fall over and die. The field is often affected by the disease in circular or irregular patches. Damping-off of seedlings is a problem in heavy, wet soils during cool periods. In older seedlings or on established plants, a reddish-brown, water-soaked lesion may develop on the roots. In severe cases, root lesions become black, and the taproot may rot entirely. Since the plant is unable to supply water and nutrients, the plant wilts and dies. Lower leaves are yellow at first and as the disease progresses may turn reddish-brown.

Disease Cycle: Phytophthora root rot is a soil-borne disease that can result in root injury or the death of alfalfa plants. The fungus survives as thick-walled spores (oospores) that produce mobile spores in the spring that migrate and infect the plants' roots. Water is important since these mobile spores (zoospores) move in the water film between soil particles. Disease development is favoured when moderate to high temperatures occur (21°C–32°C or 70°F–90°F) during humid or wet conditions. Fields that are compacted or poorly drained are especially prone to the disease. Infection occurs as the plant emerges, therefore new seedings are most at risk. Risk declines somewhat with the age of the stand. The fungus is able to survive for many years in infected plant tissue as oospores.

Management Strategies: For fields with a history of Phytophthora root rot, use highly resistant varieties and seed treatments. Consult the current edition of the report, *Ontario Forage Crop Variety Performance,* available from your OMAFRA Resource Centre, for variety ratings for Phytophthora root rot. Refer to the OMAFRA Publication 812, *Field Crop Protection Guide,* for fungicide seed treatment recommendations. Other management practices that help in managing this disease include maintaining good soil fertility, which will promote lateral root growth, removing excess moisture through improved tile drainage and ensuring reduced compaction, avoiding other stresses such as leaf-feeding insects, weeds and untimely cuttings that may stress the plants making the plant more susceptible to *Phytophthora.* Crop rotation has little effect on this disease. For additional information, see the OMAFRA Factsheet, *Phytophthora Root Rot of Alfalfa,* Order No. 94-021, or visit the Web site at www.gov.on.ca/OMAFRA/english/crops.

Pythium Seed Rot, Damping-Off or Seedling Blight

Incidence: Pythium seed rot, damping-off or seedling blight is predominantly an early-season fungal disease of alfalfa. Infection of alfalfa plants most often occurs from the time of planting to several weeks after emergence. The fungus is present in most soils in Ontario.

Appearance: Infected seeds may rot, and severely infected seedlings may wilt, collapse and die. Look for wet or watery lesions on the roots and hypocotyl of infected plants. A girdling, pinching or damping-off of the stem, at the soil line, may be seen causing the seedling to fall over and die. The field is often affected by the disease in circular or irregular patches.

Disease Cycle: Pythium seed rot, damping-off or seedling blight is closely related to Phytophthora root rot. Both produce mobile spores that move through the water film between soil particles to locate and subsequently infect alfalfa roots.

Management Strategies: Refer to OMAFRA Publication 812, *Field Crop Protection Guide,* for fungicide seed treatment recommendations. Drain excess moisture and avoid compaction. Plant when soil and weather conditions favour rapid emergence and early growth of seedlings. Increase plant populations to compensate for any plant losses.

Anthracnose (Alfalfa)
Northern Anthracnose (Red clover)

Incidence: In alfalfa, anthracnose occurs mostly in the extreme southwest portion of the province, whereas northern anthracnose is more widely distributed in red clover fields. Losses in both alfalfa and red clover due to anthracnose can be as high as 25%.

Appearance: Although symptoms can occur on the stem and leaves, it is the damage to the crown area that is most important. Stem symptoms on resistant varieties are small, black, irregular-shaped lesions, whereas lesions on susceptible varieties are large, sunken and oval-to-diamond-shaped. These lesions have a tan-to-straw-coloured centre with a dark brown border. When the fungus reproduces, the centre of those stem lesions produced on susceptible varieties will contain small, black, fruiting bodies. These can be easily seen with your eye or a simple hand lens. In severe cases, the lesions will join together and eventually girdle the entire stem, causing wilting or killing the stem. Dead stems and leaves (shoots) become white and have a characteristic shepherd's hook appearance. These are scattered through the field and are often confused with two other diseases (Rhizoctonia crown rot or Fusarium wilt) or from frost injury.

Damage to the crown appears as a blue-black discolouration of the crown tissue. Infected plants are easily broken at the base. If the diseased tissue is light brown, the cause is most likely not anthracnose but either Rhizoctonia crown rot or Fusarium wilt (see Plate 97 on page 291). Crown infection results in fewer stems per plant and eventually plant death.

In red clover, northern anthracnose can be very destructive. Besides most of the symptoms described above, infection can result in cracking of the stem surface.

Disease Cycle: The fungus thrives during coolish-warm, humid weather conditions and survives in diseased stems, leaves or debris. Spores produced in the spring are spread by rain. The rain causes splashing, which moves spores from infected plants to neighbouring plants. The fungus can be spread from field to field, for example, through equipment, soil and water erosion.

Management Strategies: Varieties with moderate-to-high resistance to anthracnose are available. Clean harvest equipment between fields. Crop rotation has been found to have limited success in managing the disease in alfalfa but has had better success in red clover, which does not have the same degree of resistance.

Common Leaf Spot
Leptosphaerulina (Lepto) Leaf Spot

Incidence: Although both these leaf spot diseases occur in Ontario, common leaf spot is the more destructive. Leaf spot infection can cause premature leaf loss and thereby reduce the quality of hay, yield, health and vigour of the crop.

Lepto leaf spot can be confused with common leaf spot since leaf symptoms begin as small, black spots (1–2 mm) that have a light tan or brown centre. A yellow halo usually surrounds the leaf spots. Unlike common leaf spot, these lesions will join together to form larger lesions (see Plate 98 on page 291).

Appearance: Leaf spot diseases are first seen on the lower leaves and then develop or move up the plant. Common leaf spot produces small, circular (1–2 mm) leaf spots that are brown to black. These lesions rarely join together to form larger lesions. Lesions on the upper leaf surface often have a raised centre. Within these raised centres, the black fruiting bodies (bumps) are easily seen with a hand lens. If you are not sure, put some infected leaves into a plastic bag with some wet paper towels. This will help speed the production of these fruiting bodies. Infected leaves become yellow (chlorotic) and drop prematurely.

Disease Cycle: Cool, wet weather favours leaf spot development, so it is found primarily in the early cuttings (spring and early summer) and regrowth (fall). These fungi survive in infected leaves and on dead leaves found on the soil surface. Spores produced on living and dead leaves are spread through the air where they infect new growth. Young leaves are the most susceptible to leaf spot diseases.

Management Strategies: Timely harvesting of forages is important to reduce leaf loss and minimize disease in the regrowth. Some varieties tolerant of common leaf spot are available, but no resistance or tolerance to lepto leaf spot has been found. There are few practical control strategies available for leaf spot diseases in forages. Leaf spots can reduce the protein level in legume leaves, so it is important to balance the time of harvest between the optimum stage for highest protein (bud stage in alfalfa) and the level of leaf spot disease.

Bacterial Wilt

Incidence: Bacterial wilt has historically been one of the most important forage diseases not only in Ontario but anywhere they are grown. The development of resistant varieties has made the disease less common.

Appearance: Symptoms become apparent as the stand gets older (3 or more years). Infected plants are stunted and have a yellow-green colour. In severe cases, the plant has spindly stems with small, distorted leaves. Infected plants that are stressed by water, heat or both will wilt or die and are scattered throughout the stand. Infection stresses the plant and increases its susceptibility to winterkill. Cutting the taproot in half (in cross-section) will show a light brown-to-yellow discolouration of the vascular tissue near outer edge.

Disease Cycle: This disease is caused by a soil bacteria that survives in diseased alfalfa roots and in plant debris for at least 10 years. Infection occurs through wounds to the roots and crown or through cut stems. The bacteria causes the plant to wilt since it grows in the water-conducting tissue (vascular system) of the plant, thereby blocking water and nutrient movement in the plant.

Management Strategies: All recommended varieties are resistant to the disease. Since the bacteria can be spread through wounds, it is recommended to cut young, less-susceptible stands first and then move to older stands. Stands should be cut when the plants are dry. This will limit or reduce potential spread from infected to non-infected plants. The bacteria can be spread in seed and hay.

Aphanomyces Root Rot

Incidence: Aphanomyces root rot has increased over the past 10 years in Ontario, especially in heavy, wet soils.

Appearance: Aphanomyces root rot causes symptoms on both seedlings and older plants. Infected seedlings are stunted and have yellow leaflets and cotyledons. Roots and stems are grey and water-soaked in appearance. Severely infected seedlings turn light to dark brown. Older or established plants that are infected are stunted and yellow and have a reduced root system. These symptoms are often confused with nitrogen deficiency. Regrowth of infected plants is slow following harvest and winter.

Disease Cycle: The fungus survives in the soil on infected plants or debris. For infection to occur, the soil must be saturated. Disease development is favoured when moderate to high temperatures occur (16°C–30°C or 61°F–86°F) during humid or wet conditions. Fields that are compacted or drain poorly are especially prone to the disease. Infection occurs as the plant emerges, so new seedings are most at risk. Risk declines somewhat with the age of the stand.

Management Strategies: Aphanomyces root rot is best managed through resistant varieties. Since saturated soils are needed for disease establishment, improving soil drainage and reducing compaction will reduce the disease.

Other Crown and Root Rots in Alfalfa and Red Clover

Stresses such as leaf diseases, insects, frequent or untimely harvests, winter conditions and low soil pH increase the severity of crown and root rots. Stresses during the growing season render the plants more susceptible to winter stress. Good crop management practices, especially a good harvesting schedule, and maintenance of adequate soil fertility and proper pH help to reduce disease severity. Control leafhoppers in alfalfa. Avoid mechanical injury of the crowns as much as possible. Crowns are easily injured by machinery and by livestock tramping, especially when the soil is wet.

Other Crop Problems

Forage Winterkill

Winterkill of forage stands can cause serious problems on livestock farms and can be a limiting factor in alfalfa production. It can result in lower quality feed, shortages of feed, disruption of the rotation and additional costs for reseeding lost stands. With forage production, it can sometimes be difficult to optimize the competing demands of quality, yield and persistence. Farmers need to determine how much forage persistence they need and then try to manage the risks accordingly.

Causes of winterkill include:

- smothering due to flooding or ice sheet formation
- heaving caused by freezing and thawing and inadequate drainage
- root injury due to low temperature
- low fertility
- poor cutting management
- disease and insect

Some forage species are hardier than others. Much of the concern over winterkill centres around alfalfa. The legumes birdsfoot trefoil, red clover, wild white clover and alsike will tolerate more adverse winter conditions than will alfalfa or ladino clover. The grasses timothy, reed canarygrass, bluegrass and bromegrass rarely winterkill. Thus their use in mixtures gives stand insurance. Orchardgrass and perennial ryegrass may be killed by icing or low temperatures.

Hardening is the process of cold tolerance development initiated by shorter fall days and cooler temperatures. During the hardening process, plants store carbohydrates in crowns and taproots. The starch is converted to sugars, which gives the plants some protection from freezing. Plants also lose some cellular water to reduce freezing damage. Long fall periods with cool, dry, sunny conditions favour winter hardening.

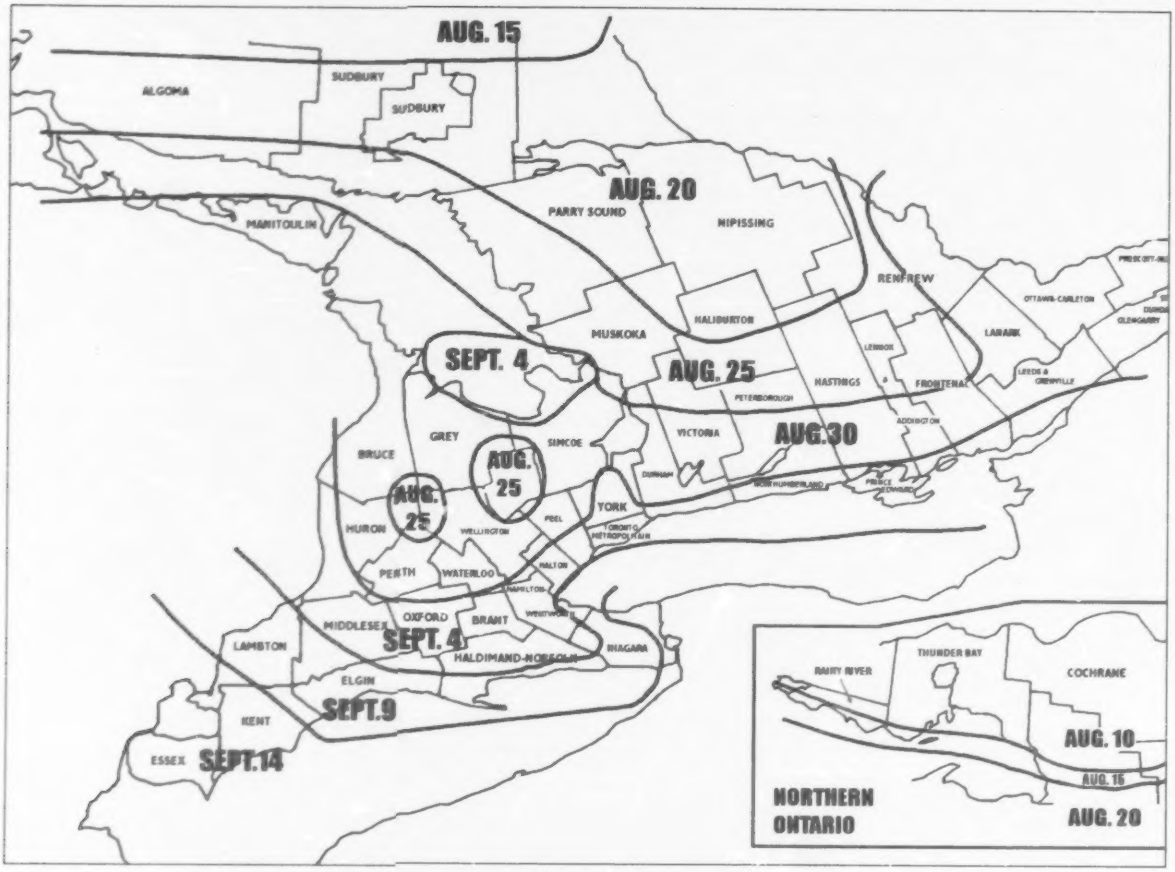
AUG. 15
ALGOMA
SUDBURY
SUDBURY
AUG. 20
PARRY SOUND
NIPISSING
MANITOULIN
RENFREW
OTTAWA-CARLETON
LANARK
HALIBURTON
MUSKOKA
LENNOX
SEPT. 4
AUG. 25
HASTINGS
FRONTENAC
LEEDS & GRENVILLE
PETERBOROUGH
ADDINGTON
VICTORIA
AUG. 30
GREY
SIMCOE
BRUCE
AUG. 25
DURHAM
NORTHUMBERLAND
PRINCE EDWARD
AUG. 25
HURON
WELLINGTON
PEEL
YORK
TORONTO METROPOLITAN
PERTH
WATERLOO
HALTON
HAMILTON-
WENTWORTH
OXFORD
BRANT
MIDDLESEX
SEPT. 4
LAMBTON
HALDIMAND-NORFOLK
NIAGARA
ELGIN
SEPT. 9
KENT
ESSEX
SEPT. 14
THUNDER BAY
RAINY RIVER
COCHRANE
AUG. 10
AUG. 15
NORTHERN ONTARIO
AUG. 20

FIGURE 5–4.
Start of the Critical Fall Harvest Period for Alfalfa

Factors That Affect Winter Survival

Critical Fall Harvest Period for Alfalfa

Harvesting before the "critical fall harvest period for alfalfa," also known as the "fall rest period,' allows the plants to regrow and build sufficient root energy reserves for overwintering. Adequate root reserves are necessary for winter survival and persistence, as well as vigorous spring growth and good first-cut yields. The critical fall harvest period is approximately 6 weeks long and varies with location. See Figure 5–4, *Start of the Critical Fall Harvest Period for Alfalfa*, above, for a map detailing the critical fall harvest period in your area. The risk of alfalfa winterkill increases by harvesting during this period and should be weighed against the immediate need for forage. Yield sacrificed by not harvesting during the critical fall harvest period is usually easily regained in first-cut yield the following year.

To ensure persistence and succeeding yields, do not harvest alfalfa during 6-week period following the date shown on the map for each region.

Winter-Tolerant Alfalfa Varieties

Refer to the *Ontario Recommended Forage Variety Performance* list available at OMAFRA Resource Centres or on the Internet at www.plant.uoguelph.ca/performance_recommendations/ofcc/ofcc.htm. High alfalfa yield indexes in the third and fourth year indicate high relative persistence. This is a composite measure of a number of production characteristics, including winterhardiness, cold tolerance, disease resistance and yield. In general, varieties that have "resistant" or "highly resistant" ratings for disease have a lower risk of winterkill.

Snow Cover

Adequate snow cover of at least 15 cm (6 in.) insulates the alfalfa crown and root at moderate temperatures. Soils with a lack of snow cover can expose alfalfa crowns to temperatures less than –15°C (5°F). This results in freezing damage to plant cells and eventual plant death. The insulation effect from snow also reduces soil temperature fluctuations and risk from heaving. Fluctuating winter temperatures with lows below freezing and highs greater than 5°C (41°F), without snow cover, can cause plants to break dormancy and become more susceptible to freezing.

Ice Sheeting

The fast melting of snow followed by cold temperatures results in ice sheeting, which smothers the plants by restricting oxygen. Ice sheeting also causes freezing due to the poor insulating ability of ice.

Leave Fall Growth to Hold Snow

After a hard fall frost, alfalfa can be harvested without lowering root reserves, but there are disadvantages. Leaving the fall growth will aid in catching snow, which insulates the soil from cold temperatures. The stubble also helps alfalfa plants survive ice sheeting by protruding through the ice, allowing the movement of air for respiration. Unlike grasses, fall regrowth of alfalfa does not cause "smothering," but ice sheeting does.

Soil Drainage

Both surface and subsurface drainage are essential to alfalfa winter survival. Heaving occurs on heavy soils with poor drainage since repeated freezing and thawing cause the taproot to be pushed out of the soil (see Plate 99 on page 291). Plants heaving more than 1 in. will dry out and have broken taproots and lateral roots, and elevated crowns. These plants will die or be severely stunted. Surface drainage is a bigger issue on flat land than on rolling land, because with frozen ground, the water cannot drain off the field, resulting in ice sheeting.

Cutting Management

Frequent harvests with short cutting intervals put stress on alfalfa that can reduce winter survival and first-cut yield the following year. Conversely, a long interval between cuttings will rebuild plant reserves and enhance winter survival. Some growers place more emphasis on high-yielding, frequently cut, high-quality stands that last for 3 years and are less concerned about alfalfa persistence. Cutting intervals of less than 35 days between cuts increase the risk of winterkill. Allowing the final cut to show some flower before harvest to ensure adequate root reserves can be a compromise between quality and winter survival.

Soil Fertility and pH

A low soil potassium level is a major factor leading to loss of alfalfa in a stand, particularly on loams and sandy loams. Adequate soil potassium levels allow alfalfa to store sufficient carbohydrates in the roots to resist low temperature injury and act as the energy source for vigorous spring growth. Forage fields should be soil sampled regularly and fertilized according to recommendations. The fertilizer should be applied before the start of the critical fall harvest period to allow for sufficient plant uptake.

Table 5-16.
Minimum Number of Healthy Plants per Square Foot Required for a Desirable Alfalfa Stand

	Plant Count	
	Plants per m^2	**Plants per foot^2**
New seeding	215	20 +
Year 1	129–215	12–20
Year 2	86–129	8–12
Year 3 or older	54	5

However, high soil potassium levels can result in luxury consumption of potassium by alfalfa and subsequent nutritional problems when fed to dairy cows prior to calving. Potassium applications on soils testing over 150 ppm will not significantly increase winter hardiness and are not recommended.

Boron deficiency can also lead to stunted alfalfa growth during midsummer dry periods and thus weaker plants going into winter. For soils low in pH, lime should be added the year prior to seeding (see the section *Fertility Management*, on page 148).

Management of Insect and Disease

Severe infestations of disease and insects that result in reduced stand vigour, reduced root reserves, and slow regrowth will increase the risk of winterkill. Potato leafhopper control can be important in reducing winterkill, particularly in the seeding year (see the section *Potato Leafhopper*, on page 165).

Assessing an Alfalfa Stand for Winter Survival

Future yield potential can be estimated by looking at plants or stems per square metre, but the health of crowns and roots is extremely important. Stem counts are more accurate than plant counts, but in earlier spring it may only be possible to count the number of crowns. Be prepared to replace an older stand if it has less than 43 plants/m (4 plants/ft^2). See Table 5-16, *Minimum Number of Healthy Plants per Square Foot Required for a Desirable Alfalfa Stand*, above.

OTHER CROP PROBLEMS

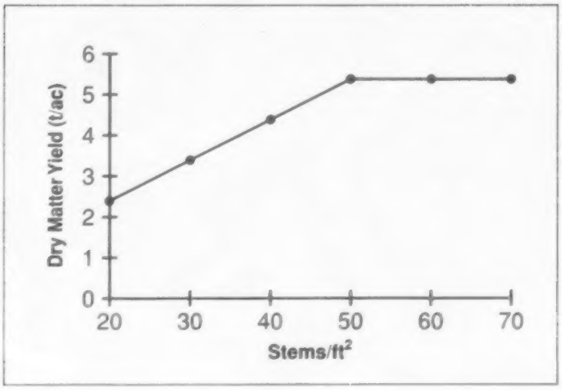

Figure 5-5.
Alfalfa Yield Potential at Various Stem Count Densities
Source: Undersander and Cosgrove, University of Wisconsin, 1992.

Dig several plants to determine the health of the crown and root. Healthy crowns are large and symmetrical and have many shoots. Cut a root open lengthwise. Healthy roots will have a white or creamy colour inside, and are firm and resistant to pealing when scratched with your thumbnail. Dying plants will have a discoloured crown and root and a spongy texture. Check for bud or new shoot vigour. Plants with broken taproots from heaving may green up but die later. Slightly heaved plants can survive, but their longevity and productivity will be reduced.

When alfalfa is about 15 cm (6 in.) in height, stems/m^2 (stems/ft^2) can be used as the density measure. Stem density of 590 stems/m^2 (55 stems/ft^2) has good yield potential (see Figure 5-5, *Alfalfa Yield Potential at Various Stem Count Densities*, left). There may be some yield loss with stem counts between 431-539 plants/m^2 (40-50 plants/ft^2). Consider replacing the stand if there are less than 40 stems/ft^2 and the crown and root health is poor.

Other considerations include forage inventories and requirements, alternate forage options, how much grass is left in the stand, rotational requirements and weed pressure.

6. Cereals

Cereal crops are grown on approximately 25% of the field crop acreage in Ontario. Less management attention is often given to these crops than to corn or soybeans. Historically, cereals have been used as rotation crops and for home-grown feed. With attention to detail and good management, profit from cereal crops can be increased.

Tillage

Tillage Options

Cereal crops do not respond significantly to tillage (see Table 6–1, *Winter Wheat Yield Response to Tillage Systems 1986–89*, right, and Table 2–3, *Tillage System Effects on Crop Yields at Woodstock, Ontario (1996–2000)*, on page 17). Research comparing the yield response of winter wheat to various tillage options demonstrated that no yield advantage among moldboard plowing, minimum tillage and no-till systems was observed. While yields are not affected greatly by tillage systems, good seed-to-soil contact and soil moisture for germination are essential.

The selection of a tillage system will impact other factors in the system. The tillage method chosen must fit with factors such as fertility, insect pressure, disease incidence and weed control for producing high-yielding, profitable crops.

Risks associated with more intensive tillage in winter crops include greater frost-heaving potential and increased risk of snow mould. Erosion is a concern with tillage in all crops.

Seeding options for cereals range from aerial seeding to frost seeding.

No-Till Seeding

Most winter wheat is now grown using a no-till system. No-till wheat yields are often equal to yields obtained with conventional tillage. No-till drills can follow the combine in the same field, which advances seeding date and increases yields. No-till planted winter cereals are better able to resist frost heaving, as the plant anchors itself in firmer soil.

Table 6–1.
Winter Wheat Yield Response to Tillage Systems 1986–89

Tillage Systems	Comparative Yield[1] t/ha	Comparative Yield[1] bu/ac	No. of Paired Comparisons
Moldboard vs. minimum	4.90 vs. 5.01	72.9 vs. 74.6	141
Moldboard vs. no-till	3.93 vs. 3.90	58.4 vs. 58.1	42
Minimum vs. no-till	4.23 vs. 4.19	63.0 vs. 62.4	111

Source: Tillage 2000 final report, Aspinall and Kachanoski.

[1] Average yields vary because comparisons come from a range of sites.

The success of a no-till system requires consideration of fertilizer management, drill capability and weed control. No-till crops show more response to seed-placed starter fertilizer, especially phosphorus, compared to conventional tilled crops.

No-till crops grown without starter fertilizer will often develop the "corn row syndrome" (see the section *Fertility*, on page 188, and Plate 100 on page 291). Wheat plants growing over old corn rows will be significantly taller and more vigorous than plants growing between the rows. This is a result of the higher phosphorous availability from the corn starter fertilizer band, even though the corn crop was grown 2 or 3 years prior to the wheat crop (see Table 6–2, *Corn Row Syndrome*, on page 176). Winter wheat is one of the most responsive crops to phosphorous fertilization (see Table 6–3, *Yield Response to Fertilizer Rate*, on page 176).

Seed-to-soil contact is critical for moisture uptake. No-till drills must be able to penetrate into hard soil and through residue to accurately place seed. Add seed-firming wheels or plastic "hockey stick" seed firmers, which will press the seed into the bottom of the seed trench, helping to increase seed-to-soil contact and improving the uniformity of seed depth placement.

Table 6–2.
Corn Row Syndrome

	Phosphorous Soil Test	Height cm (in.)	Tissue Phosphorous Levels: % P (DM Basis)	Yield t/ha (bu/ac)
In row	19	107 (42)	0.16	5.13 (76.3)
Between row	9	89 (35)	0.12	4.51 (67.1)
One site with 5 gal. liquid on wheat				
In row	18	109 (43)	0.17	5.02 (74.7)
Between row	13	102 (40)	0.15	4.92 (73.2)

With 100 lb. MAP (monoammonium phosphate), no difference in visual growth. Ontario data, eight locations, OMAFRA.

Weed control is critical in no-till systems as discussed in the section *Weed Control*, on page 196. A burndown before planting ensures control of dandelions and other winter annual weeds and should be a standard practice. Refer to OMAFRA Publication 75, *Guide to Weed Control*, for burndown recommendations. To reduce disease incidence, use a fungicide seed treatment. For further information on seed treatments, refer to the OMAFRA Publication 812, *Field Crop Protection Guide*.

In dry soils, the addition or use of tillage coulters may show some benefit in a no-till system. Slight loosening of dry, hard soils allows for better, more rapid root development and growth. In a wet fall season, light tillage may speed soil drying and allow for planting in better conditions. These limited tillage methods should be used when soil conditions dictate. It is important to take the necessary steps to create a proper seedbed and get the crop seeded as quickly as possible.

Conventional Tillage

Cereals have been grown for generations using the plow, disc and cultivator for seedbed preparation. Most spring cereals are still grown using conventional tillage. While this system works well, the potential erosion concerns and lack of yield response to tillage have shifted acreage towards a reduction in tillage. The guidelines regarding seed-to-soil contact, planting into moisture and seeding depth accuracy are consistent with the no-till section. The tillage operations replace the herbicide burndown.

Frost Seeding of Spring Cereals

Seeding spring cereals into frost is a relatively new technique in Ontario that can significantly advance seeding dates and potentially increase yields. This strategy has been used extensively and with great success in other regions of North America.

Table 6–3.
Yield Response to Fertilizer Rate

		Monoammonium Phosphate (MAP) kg/ha (lb/ac)			BDCST kg/ha (lb/ac)
	Zero Fertilizer	56 (50)	112 (100)	224 (200)	224 (200)
Average Yield: t/ha (bu/ac)	5.27 (78.4)	5.56 (82.7)	5.67 (84.4)	5.66 (84.2)	5.39 (80.2)

(Average of 12 sites, 2001)

"Frost seeding" means seeding cereals into a light frost in early spring. After the snow has melted, and the frost is out of the ground, there are often several cold nights with below-zero temperatures. Seeding into this light frost is possible, as the frost will support the tractor and avoid compaction or rutting. It is not essential to close the seed trench when frost seeding, as the soil will naturally fall in and cover the seed as the frost comes out of the ground. Simply set no-till equipment to make a shallow (2.5-cm or 1-in.) seed trench and firm the seed into the bottom of the trench.

The window of opportunity for this method of seeding is short. Frost is generally not hard enough until 2:00–4:00 a.m. and is out of the ground by 8:00–10:00 a.m. **Do not attempt this method of seeding when air temperatures drop below –8°C.** The ground will be frozen hard enough to break the no-till equipment.

While this may be a narrow window and may not occur every year, the increase in yield from early planting using this technique can be as much as 25%.

Aerial Seeding Winter Wheat

In short-season areas or in late wet seasons, consider aerial seeding. Aerial seeding is most successful when seed is flown on before 10% of the soybean leaves have dropped. The dropping soybean leaves will provide some cover and help retain moisture for wheat germination.

Results from aerial seeding have been disappointing. The seed is extremely vulnerable to slug damage. Slugs feed on the germ of the kernel, which can decimate the stand, particularly on headlands. The seed will appear to still be on the surface, as if waiting to germinate, but on closer examination, the damage to the kernel becomes evident. Reseeding of headlands after soybean harvest can help overcome this problem.

The shallow root system that develops from aerial-seeded wheat is more prone to heaving injury and wind damage (see the section *Depth of Seeding*, on page 181). In the spring, wheat plants are often attached to the soil by only one hair root. If this hair root breaks as plants twist with the wind, the plant dies. With these inherent risks, yields from aerial-seeded wheat are generally 10% lower than from drilled wheat, according to limited on-farm trial data. Therefore, aerial seeding is not a standard practice. When conditions dictate that aerial seeding is the best option, increase seeding rates to 4.9 million seeds/ha (2 million seeds/ac) to compensate for stand loss.

Broadcast Seeding

Winter or spring cereal seed can be broadcast to speed up the planting process. It is important to get good seed-to-soil contact and a uniform seeding rate across the width of the spread pattern and between passes of the spreader.

Use airflow units to achieve the uniform spread pattern. Till fields at a shallow (7.5-cm or 3-in.) depth, twice at right angles and, finally, packed. This will help prevent streaking in the seeding pattern and improve seed-to-soil contact.

Depth of seeding is inconsistent with this method. Variable maturity and a 5%–10% reduction in yield often occur. If broadcast seeding, increase seeding rates by 10% to compensate for the potential variability.

Variety Selection

The principles of selecting a winning variety do not vary greatly from crop to crop. Confounding factors with wheat variety selection are quality and market class. Ontario grows more types of wheat than any other province or state in Northeastern North America.

Oats may have quality factors attached to them in the future, if the market for milling oats expands. Barley could also have quality premiums, should a malting barley market develop in the province. Currently, only wheat has premium market opportunities.

Standard Variety Selection Criteria

- Use all information sources available. Cereal crops have an excellent performance testing system. This information is available in factsheets produced annually by OMAFRA that can be found on the Web site at www.gov.on.ca/OMAFRA/english/crops. Variety comparisons are also available on the Ontario Soil and Crop Improvement Association's, Ontario Farm Trials On-line (OFTO) system, available at www.ontariosoilcrop.org.
- Select two or three of the best available varieties. It is always good management to spread the risk. Selecting different varieties reduces disease potential and spreads the harvest workload.

Compare varieties for potential yield, standability, disease tolerance and all other agronomic factors. Understand the main problems of your farm and select varieties accordingly.

Select varieties based on the needs of your own growing conditions. Refer to the variety characteristics table from the Ontario Performance Trials Factsheet available at www.gov.on.ca/OMAFRA/english/crops.

Use long-term data over many locations when comparing variety performance. Often, varieties that are outstanding under one set of environmental conditions one year suffer considerably under the next year's environmental conditions. For example, an oat variety that excels in a year without rust pressure may be the worst performer the year rust hits early. Using long-term, multi-site data will lead to the selection of the best, yield-stable varieties.

Winter Wheat Dormancy

Dormancy, or sprouting resistance, varies greatly between varieties. Several genes are responsible for the dormancy factor in wheat. One of the strongest of these genes is linked to the genetic coding for red wheat or the red colouration of the bran. In general, red wheat varieties will not sprout as readily as white wheat varieties, and often hard red wheat varieties will sprout less readily than soft red varieties.

In the past, bearded white wheat varieties were most susceptible to sprouting. However, genetic improvements are changing this scenario. Some bearded white wheat varieties (e.g., 25W33) now have a sprouting tolerance almost equal to the tolerant soft red varieties (e.g., Mendon). In the future, white wheat varieties will likely be developed that have as much dormancy as today's hard red varieties.

Sprouting tolerance should not be confused with germination of the crop once planted. Dormancy is dependent on time, light and temperature. By the time the seed is planted in the fall, time has passed, and the dark, cool conditions of the soil overcome the dormancy factors.

The speed of emergence after planting is entirely related to seed vigour of the variety and seed lot. Emergence has nothing to do with sprouting tolerance. In fact, in variety performance trials, some soft red varieties often emerge before soft white varieties.

It is a myth, then, that the red wheat varieties must be seeded before the white varieties in the fall.

Factors Unique to Cereal Crops

Straw

In some livestock regions, the need and value of straw can be almost equal to the value of the grain. Straw quality is also a factor. Moisture absorbency is a factor for most livestock bedding. The horse industry is only interested in "dust-free" straw. Straw has been one of the driving forces for growers to continue growing barley rather than spring wheat, even though the economics of grain production would favour spring wheat.

In general, two-row barley varieties produce more straw than six-row varieties. Oat straw quantity and quality are good. Wheat straw is less absorbent than oat or barley straw, and there is less straw produced by most spring wheat varieties than by spring barley varieties.

Growers who need and value the straw can also increase its quality by using fungicides to control crop diseases. This is especially important for providing dust-free straw to the horse industry. Consider winter barley for higher yields of barley straw if growing in an area where winter survival is not a problem.

Straw Quantity
The crops below are listed in order of which produces the most straw:

1. winter wheat
2. winter barley
3. two-row spring barley
4. mixed grain
5. spring oats
6. six-row spring barley
7. spring wheat

Straw Quality
The crops below are listed in order of which produces the best straw:

1. two-row spring barley
2. six-row spring barley
3. mixed grain
4. spring oats
5. winter barley
6. spring wheat
7. winter wheat

Market Class

Within wheat, the number of market classes continues to increase (see Table 6-4, *Characteristics of Various Cereal Market Classes*, on page 179). Since the mid-1980s, when only spring feed wheat and soft white winter wheat were grown in Ontario, the market has expanded to include many more classes. This increase in wheat classes is likely to continue, with new specialty wheats and hard white spring wheat varieties in development. Many of these market classes have yield and price premium implications that must be considered when selecting varieties. For example, high protein, non-pastry wheat varieties generally have a yield penalty (approximately 10%) associated with achieving higher protein. However, these varieties have a price premium (see Table 6-5, *Wheat Protein Premiums for Hard Red Winter and Spring Wheat Varieties*, on page 180). It is much easier to achieve high protein and earn these price premiums on farms with more inherent soil nitrogen (i.e., livestock farms with manure and/or forages). On cash crop farms, it often takes significantly more nitrogen to achieve optimum protein levels in these non-pastry wheat varieties (see the section *Fertility*, on page 188). All these factors must be considered when selecting varieties.

In 2001, the price premium for hard red winter wheat varieties was approximately $10.00 per tonne over the soft winter wheat varieties.

Cereal Species

Barley

All barley has the genetic potential to develop six rows of grain in the head (six-rowed barley). Two-rowed barley only develops two of these rows. In general, two-rowed varieties are larger seeded, shorter and more resistant to lodging, leaf rust and mildew. Two-rowed varieties often mature later and have lower yields than six-rowed types. Six-rowed varieties usually have better resistance to scald and are more tolerant of heat and moisture stress, making them more tolerant of late planting. The more open canopy of six-rowed types makes them less competitive for underseedings, while the lodging resistance of two-rowed types must be taken into account when underseeding.

Winter Barley
Both spring and winter types of barley are grown in Ontario. Winter barley requires a period of cold temperatures to "vernalize" the plant and initiate flowering and grain development. Winter barley planted in the spring will not produce grain. Spring barley does not require this vernalization process.

Table 6–4.
Characteristics of Various Cereal Market Classes

Market Class	Traits and Uses	Characteristics
Soft white winter wheat	Pastry wheat Low protein High yield	Susceptible to sprouting Do not over-apply nitrogen
Soft red winter wheat	Pastry wheat Low protein High yield	Do not over-apply nitrogen
Non-pastry winter wheat (Hard red winter wheat)	Bread blend wheat High protein desirable Tends to be lower yielding than the best soft varieties	Requires more nitrogen Quality more variable
Specialty winter wheat varieties	Variable	Must be maintained and identified by variety
Spring milling wheat varieties	Bread blend wheat High protein Low yield	Poor straw High price
Spring feed wheat varieties	Sometimes enters bread blend market High protein Moderate yield	Poor straw
Winter barley	High yield Poor winter hardiness Poor standability	Plant early May be difficult to thresh
Six-row barley	Good straw More heat tolerant More tolerant of late planting	Poorer grain sample Do not over-apply nitrogen
Two-row spring barley	Excellent straw Good straw volume	Do not over-apply nitrogen
Oats	Good straw	Tolerates poor drainage

Winter barley is much higher yielding than spring barley but is considerably less winter hardy than winter wheat. It survives only in areas with milder winter conditions or excellent snow cover. Winter barley must be planted earlier than winter wheat, making it more prone to barley yellow dwarf virus (BYDV) and snow mould. Winter barley matures much earlier than winter wheat, and some years may be suitable for double cropping. In areas that are adapted to winter barley production, yields of up to 8.1 t/ha (150 bu/ac) have been achieved.

Hulless Barley

Covered or hulled barley consists of approximately 10% hull and 90% kernel. With hulless types, much of the hull is removed at harvest. Hulless barley has a higher test weight and lower fibre content than covered barley. The seeds must be handled carefully, as the embryo (germ) is susceptible to damage. The amount of hull removed from the grain is somewhat dependent on weather conditions at harvest. Hulless barley will yield less than regular varieties, because the weight of the hulls is left in the field, but the concentration of energy and protein will be greater.

Oats

Oats are a traditional feed crop in Ontario, particularly for horses. Oats have better balanced protein and higher fibre content than barley. In Eastern Ontario, where buckthorn is common, leaf rust is a problem in oat production, and resistant varieties should be grown. Remove buckthorn from field margins whenever possible.

Milling Oats

Milling oats are used for human consumption and therefore must meet special quality requirements, including plump kernels, high test weight and groats (grain) that are free of discolouration and foreign matter such as insects, weeds or other crop seeds.

Hulless Oats

Hulless oats may be of interest to pig and poultry producers because the grain (groat) is approximately the same metabolizable energy content as corn. They have good quality protein and high protein content (14%–20%). Diets can be formulated with hulless oats as a major energy source and only small amounts of soybean meal, canola meal or the amino acid

Table 6-5.
Wheat Protein Premiums for Hard Red Winter and Spring Wheat Varieties

Percentage Protein (%)	Premium ($/tonne)
Hard Red Winter Wheat Protein Premiums (Based on the Year 2001 Market[1])	
10.9 or less	no premium
11.0	5
11.1	6
11.2	7
11.3	8
11.4	9
11.5	10
11.6	11
11.7	12
11.8	13
11.9	14
12.0 or greater	15
Spring Wheat Protein Premiums (Based on the Year 2001 Market[1])	
11.9 or less	no premium
12.0 to 12.4	10
12.5 or greater	18

[1] The most current wheat premiums are available on the Ontario Wheat Producers Marketing Board's Web site at: www.ontariowheatboard.com/.

lysine need be added to obtain performance comparable to a standard corn-soybean meal diet.

Hulless oats become groats when they are threshed. The thin hulls are left in the field as chaff, resulting in a weight loss of 25%–30%, compared to regular varieties where the hull is retained. Current varieties have a coating of fine hair on the groat that prevents the oats from flowing freely. These hairs cause itching, making the oats unpleasant to handle. Work is under way to develop "naked" oats that shed both the hull and these hairs at harvest.

Hulless oats can be grown like regular oats. Special attention must be paid to planting, harvesting, handling and storage of the seed to be successful. Since the hull does not protect the seed, germination is easily reduced. Care must be taken during the planting process. Embryo damage can occur during harvest and handling. The high oil content at the surface of the seed makes the seed more attractive to storage insects. Moistures should be below 10% to ensure the grain does not go "off quality" in storage.

Mixed Grains

Mixed grains occupy a large acreage in the province. Most mixed grains are a combination of oats and barley, but mixtures may include spring wheat or field peas. Mixed grains are only grown for feed.

No specific recommendations regarding the best mixtures can be made. Generally, the highest yielding varieties of oats and barley in pure stands also perform best in mixtures. Height and maturity ratings of the components of a mixture must be matched. The addition of wheat or peas to the mix will increase the energy or protein of the grain, but yields are often significantly reduced.

Leaf and head diseases are usually much less severe with mixed grains than where oats or barley are grown alone. Mixtures of oats and barley are more tolerant of variable drainage conditions, with the barley component becoming predominant in drier areas of the field and the oat component producing more in poorly drained areas.

Winter Wheat

Winter wheat is grown on the largest acreage of any of the cereal crops and is grown across most of the province. Like winter barley and winter rye, winter wheat requires vernalization, a period of cold temperature (0°C–5°C, 32°F–41°F) that induces the crop to elongate, head, flower and produce grain. While wheat vernalizes most effectively at the five-leaf stage, the vernalization process can be completed as soon as germination begins. Therefore winter wheat can be planted at any time in the fall, right until freeze-up, and still head out normally the following year. Winter wheat planted in the spring will not enter the reproductive stage, as it has not been vernalized. In some cases, winter wheat has been spring planted to give the appearance of a lawn that almost never needs cutting.

Wheat is of huge economic benefit to the Ontario economy, with a 400% increase in economic value through the processing chain. This is the highest increase in value of any agricultural commodity.

Spring Wheat

Feed Wheat

Feed wheat is a more concentrated source of protein and energy for livestock than barley or oats. Care must be taken in non-ruminant diets to limit the amount of feed wheat in the ration to avoid digestive problems. The general guideline is to include no more than 25% of the total ration as wheat. Be sure to consult a nutritionist for further information.

Some feed wheat varieties can produce yields that are competitive with oats and barley as feed grain. At times, these varieties may achieve quality that allows them to be included in the milling wheat market. Check with your seed supplier or the Ontario Wheat Producers Marketing Board to determine if a variety is generally of milling or feed quality. When feed wheat varieties do make milling quality, consider it a bonus and not something to depend on.

Milling Wheat

To ensure market acceptance, take care to grow a quality product. This includes factors such as selecting the proper variety, early planting and good weed control. Spring wheat varieties generally have a very open canopy, making weed control more critical. This open canopy makes them ideal for underseeding cereals.

Rye

Both spring and winter types of rye are available and grown in Ontario. Typically, winter rye is grown on the light sandy soils of tobacco and vegetable farms to control wind erosion and build up organic matter. Spring rye is occasionally grown as an annual forage crop. Unlike the other cereal crops, rye is quite susceptible to ergot, which is detrimental to its use as either feed or food.

Winter rye is the most winter hardy of all the winter cereals. It is extremely early maturing; well ahead of either winter wheat or winter barley. Rye is incredibly hard to thresh, and despite the early maturity is not harvested until well after wheat and barley crops. This allows the straw to become less intact and facilitates the threshing of the grain from the head.

Some producers looking for extra forage have started to plant winter rye after the corn is harvested. This rye will begin to head about mid-May the following spring, when it is cut and blown in for haylage. Soybeans or edible beans are then planted with almost no yield loss due to delayed planting. Concerns from this practice include potential allelopathic effects from the rye residue and the possibility of volunteer rye in wheat crops the following year.

Triticale and Spelt

Both triticale and spelt are grown in Ontario on a limited basis. Triticale, a cross between wheat and rye, is only grown as emergency forage when hay crops winterkill, mostly in combination with peas (see the section *Warm-Season Annual Grasses*, on page 138). Spelt, an earlier version of modern day wheat, is mostly grown under organic crop production techniques for high value special markets.

Biotechnology

Most crop plants are diploids, meaning that they have one pair of each chromosome. Both barley and oats are diploids. Wheat is a hexaploid, having three pairs of each chromosome. This has made gene transfer in wheat much more difficult. The profit margin in cereals for seed production and breeding is much less than in many other crops. Therefore, cereal crops have been significantly behind in the development of varieties having special traits from using gene transfer technology.

This situation is set to change. How the industry and consumer will respond to these changes has yet to evolve. Growers should be aware of these developments and the criteria for identity preservation and separation that may go along with any new developments.

Barley, and now wheat, have been at the forefront of new technological developments to improve germplasm from these species. Using the doubled haploid technique, developed at the University of Guelph, advancement of new varieties has been dramatically increased. This technique should ensure a continued stream of new varieties with improved quality and agronomic traits suitable for Ontario's farmers.

Planting

Depth of Seeding

Seeding depth can have a significant impact on plant development (see Figure 6-1, *Days to Emergence at Various Seeding Depths*, on page 182). Still, soil conditions at the time of planting must always dictate seeding depth. Do not plant shallow into dry soil in anticipation of rain for germination. Plant into moisture to ensure quick and uniform emergence, even if deep planting is required. However, when soil conditions are too wet, consider shallow planting or making an additional tillage pass in an attempt to dry the soil.

Cereals are lagging far behind corn and soybeans in the development and adoption of technology to accurately control seeding depth. With current drills, seed depth can vary from 1.25–7.5 cm ($^1/_2$–3 in.) in the same row, depending on soil conditions.

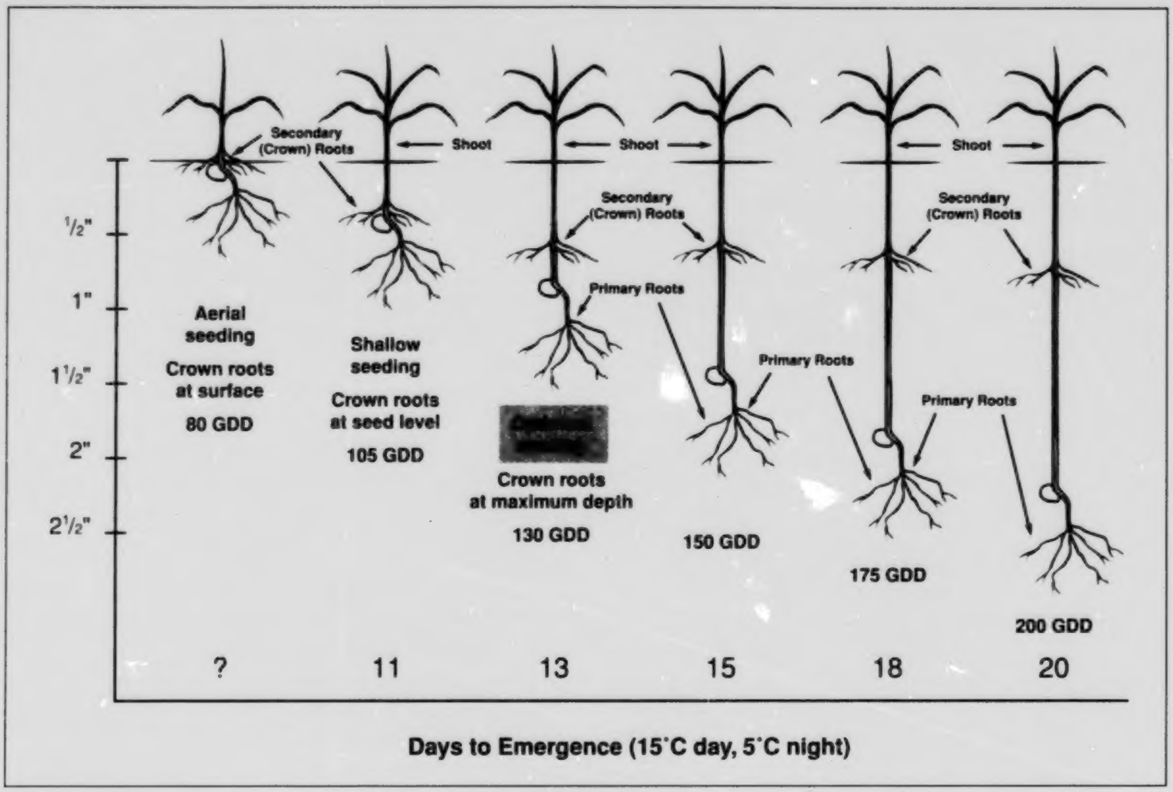
Secondary (Crown) Roots
Shoot
Shoot
Secondary (Crown) Roots
Primary Roots
Primary Roots
Shoot
Secondary (Crown) Roots
Primary Roots
½"
1"
1½"
2"
2½"
Aerial seeding
Crown roots at surface
80 GDD
Shallow seeding
Crown roots at seed level
105 GDD
[redacted]
Crown roots at maximum depth
130 GDD
150 GDD
175 GDD
200 GDD
?
11
13
15
18
20
Days to Emergence (15°C day, 5°C night)

FIGURE 6-1.
Days to Emergence at Various Seeding Depths

Growers can attempt to minimize this variation in depth by using seed firmers, which hold the seed at the bottom of the trench. Level fields and slower planting speeds will help reduce variability. Seeding depth accuracy in cereals will not match corn as long as press wheels trail double disc openers, or single coulters without parallel linkage are standard equipment.

Cereal crop yield is greatly affected by seeding depth variability and lack of accurate placement. Cereals are the most responsive crops to early, timely seeding (see the section *Planting Dates*, on page 183). When cereals are not seeded at a uniform depth or are seeded too deep, delayed emergence of 1 week or more often occurs (see Figure 6-1, above). Delayed emergence is equivalent to an equal delay in seeding date, resulting in an equal reduction in yield. It is evident that the accuracy of seeding equipment requires improvement.

Optimum Seeding Depth

Cereals should be planted uniformly at a depth of 2.5 cm (1 in.). This encourages early emergence and rapid development of an extensive secondary root system. Moisture availability is an overriding factor, and seed must be placed into moisture. A 2.5-cm (1-in.) planting depth is of little value if moisture is not available at this depth.

Growers that do an accurate job of seeding winter wheat will experience better winter survival and higher yields. Spring cereal yields will also increase using this strategy. Producers should strive to improve the seeding methodology to achieve the highest yields possible.

Cereal Development

The development of the cereal seedling can be determined by following growing degree day (GDD) accumulations. GDD calculations are discussed in greater detail in the section *Growing Degree Days*, on page 3. For cereal crops, use GDD base 0 calculations.

Generally, cereals require 80 GDDs for the seed to germinate. For emergence, 50 additional GDDs for each inch of planting depth are required.

Figure 6-2, *Cereal Growth Stages*, on page 183, shows the breakdown of cereal crop development according to the "Zadok's Scale" ("Feekes" is another cereal

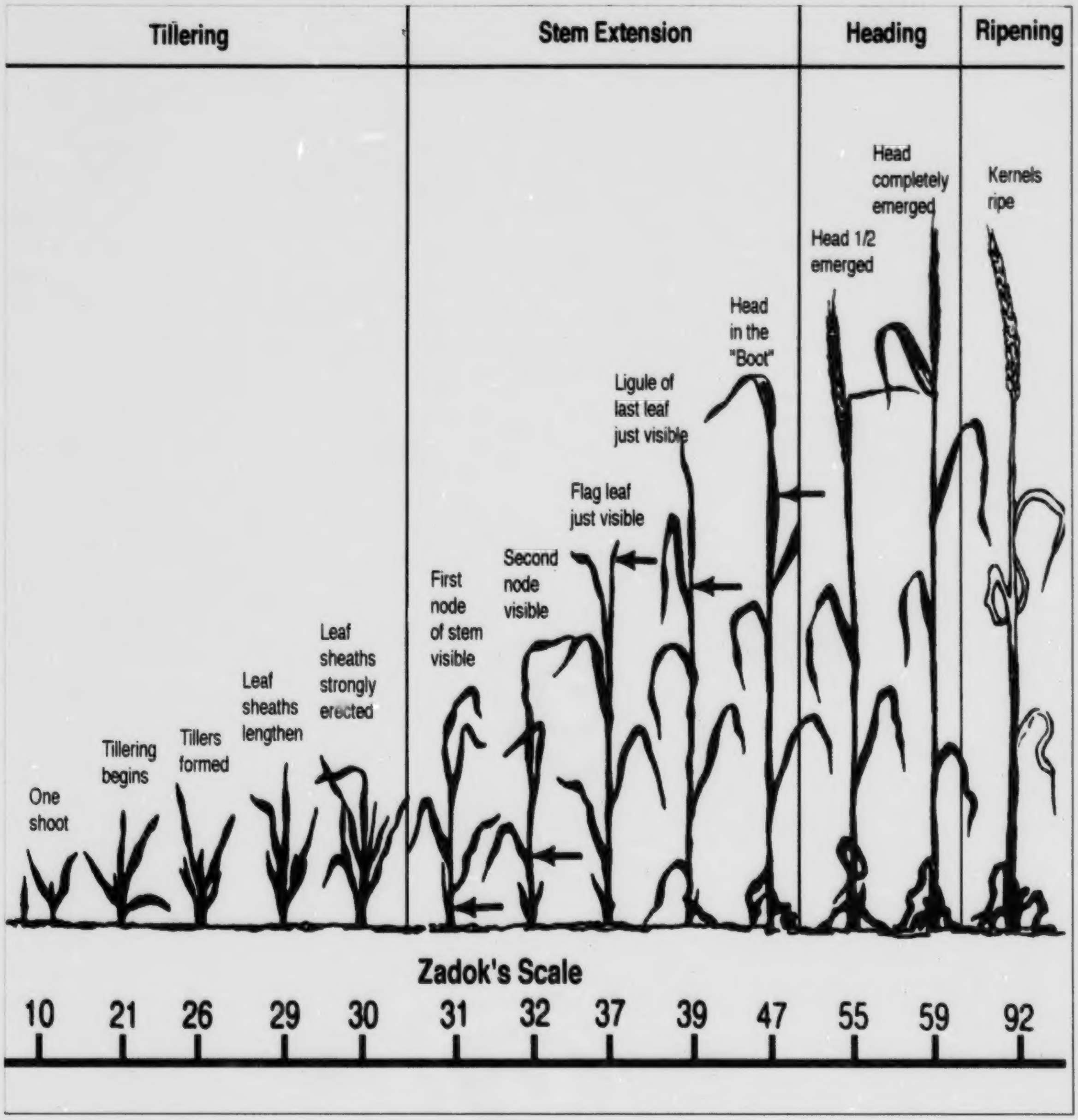
Tillering
Stem Extension
Heading
Ripening
One shoot
Tillering begins
Tillers formed
Leaf sheaths lengthen
Leaf sheaths strongly erected
First node of stem visible
Second node visible
Flag leaf just visible
Ligule of last leaf just visible
Head in the "Boot"
Head 1/2 emerged
Head completely emerged
Kernels ripe
Zadok's Scale
10
21
26
29
30
31
32
37
39
47
55
59
92

FIGURE 6–2.
Cereal Growth Stages

At typical fall temperatures of 15°C days and 5°C nights, 8 days (15°C + 5°C = 20/2 = 10 GDD/day) would be required for germination and an additional 5 days for each inch of planting depth to reach emergence. Cooler temperatures will slow this process.

development scale not shown here). These stages are critical in many management decisions that growers make. Nitrogen and herbicide applications must be completed during the tillering stage; disease control is most critical in the stem extension and heading stage. Knowing the growth stage of the crop when scouting for problems is essential to determining if control measures are warranted.

Planting Dates

Cereal crops are even more responsive to planting date than corn. Ontario research shows a 0.07 t/ha/day (1.1 bu/ac/day) decrease in yield for each day that cereal planting is delayed beyond the optimum date.

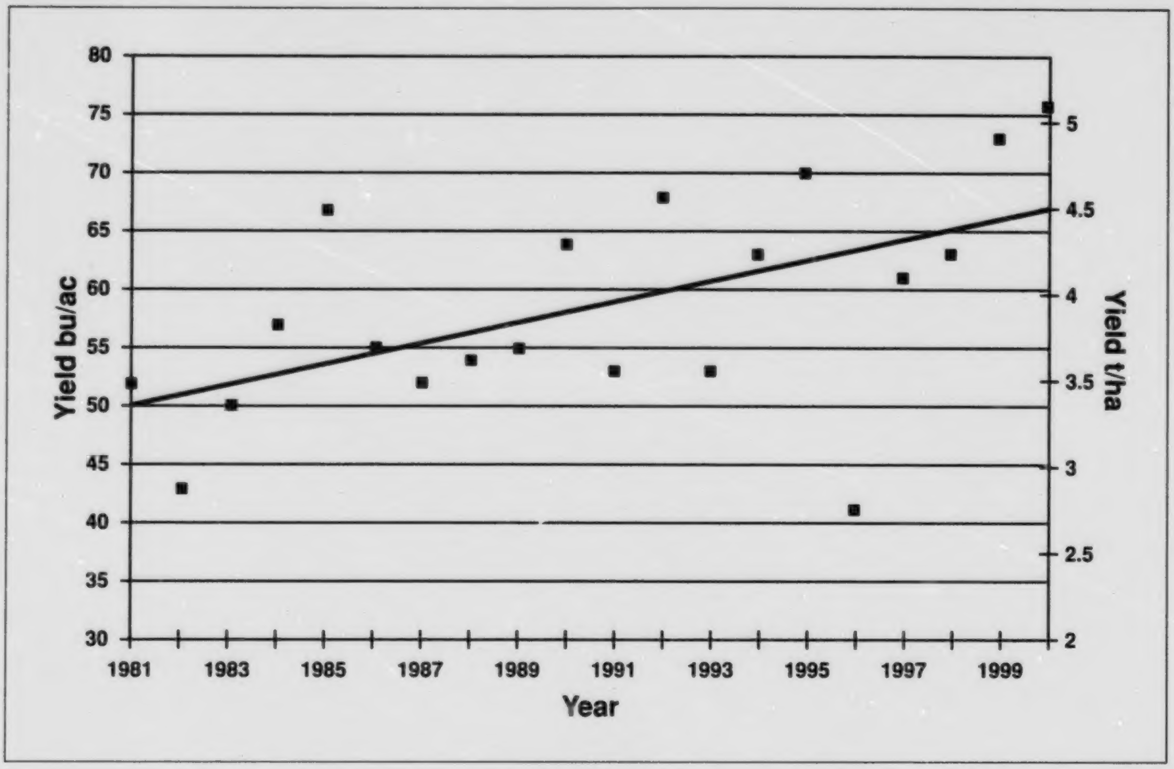

FIGURE 6-3.
Provincial Winter Wheat Yield for 1981-2000

Provincial winter wheat yields from 1981 to 2000 are illustrated in Figure 6-3, *Provincial Winter Wheat Yield for 1981-2000*, above. Record yields in 1999 and 2000 were primarily due to early planting the previous fall, while low yields in 1993 were the result of late seeding in the fall of 1992.

Winter Cereals

The seeding date for winter wheat is often determined by the date soybeans are harvested. This can delay optimal planting dates for winter wheat resulting in reduced yields. Wheat grown after soybeans is easily facilitated by following the simple guidelines outlined in the section *Winter Wheat Following Soybeans*, on page 98.

Figure 6-4, *Optimum Date to Seed Winter Wheat Across Ontario*, on page 185, shows the optimum seeding dates for winter wheat. The isolines on the map are based on average weather conditions, and actual results will vary slightly from year to year. Seed winter barley 7-10 days prior to the optimum dates for winter wheat to improve winter survival. Winter barley has much less winter hardiness than winter wheat.

Wheat can be seeded too early. Do not seed wheat more than 10 days before the optimum date to minimize Hessian fly and BYDV risk. BYDV is spread by aphids, which feed on wheat seedlings. Using insecticides to control aphids is not practical or economical. Aphids are very susceptible to low temperatures. Aphid numbers and related concerns drop off as cool fall temperatures arrive. (For more information on Hessian fly, cereal aphids or BYDV, see the section *Insects*, on page 199, and *Diseases*, on page 203).

As winter barley must be seeded early, select a variety with tolerance to BYDV.

Modern varieties of wheat do not produce excessive top growth if seeded early. While early seeded wheat may be more prone to snow mould, wheat seeded even 2 weeks before the optimum date has not had excessive top growth problems in at least 20 years.

Spring Cereals

It is virtually impossible to seed spring cereals too early, unless soil conditions are excessively wet. This tremendous response to early seeding is convincing some producers to consider frost seeding. Cool,

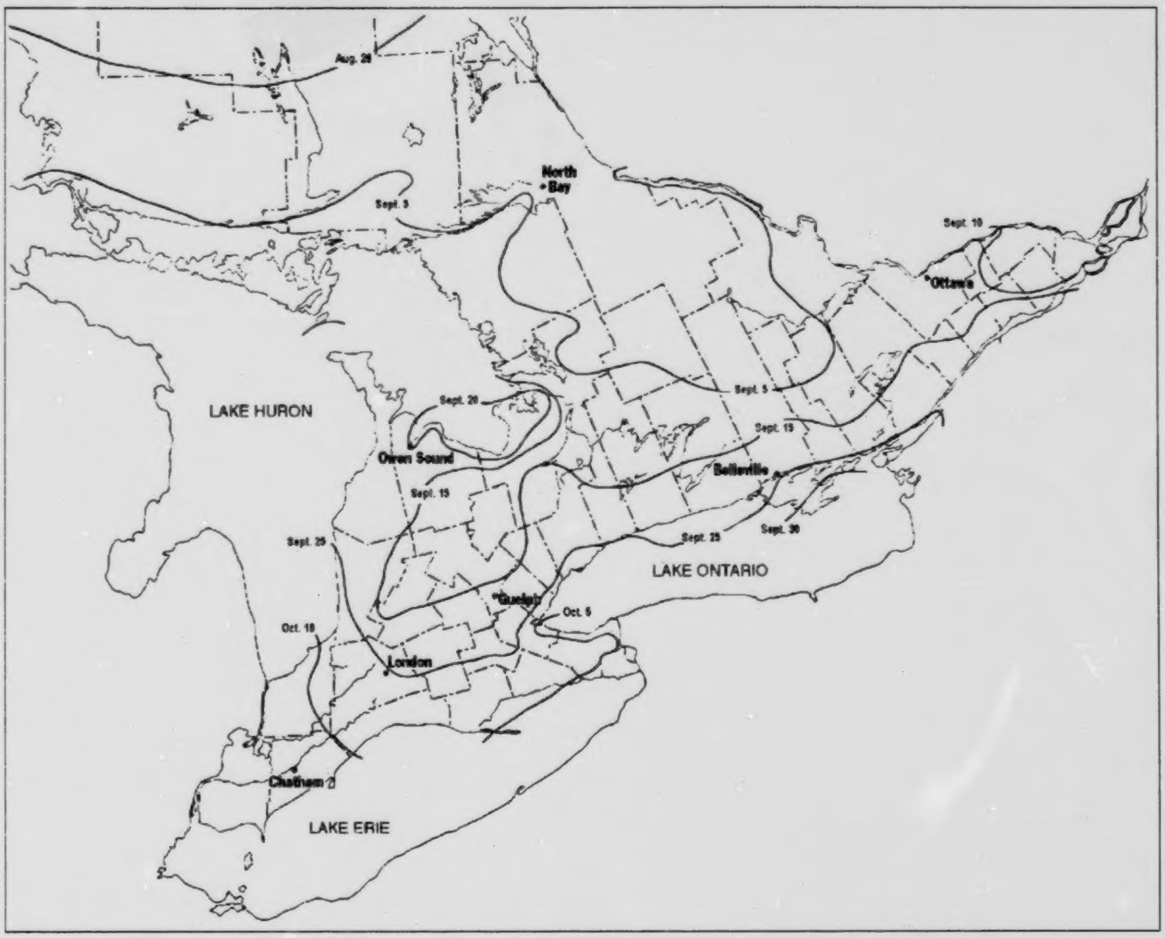

FIGURE 6-4.
Optimum Date to Seed Winter Wheat Across Ontario

moist spring conditions promote tillering and production of large heads. The flowering dates of the crop are also advanced, avoiding the hot, dry conditions that often exist in late June to early July.

The target date for planting spring cereals is April 10 for Southwestern Ontario, April 15 for Central and Eastern Ontario and May 10 for Northern Ontario. In areas of greater than 2,900 crop heat units, spring cereals are generally not recommended and should definitely not be grown if planting is delayed beyond April 20.

Replanting

Winter cereals are one of the few crops that provide a second opportunity to assess the crop in spring and replant to another crop if winter survival was not acceptable, without incurring a yield penalty. Assess the wheat crop during April and early May. The replant decision should be left as late as possible. Damaged plants will often recover under good weather conditions, while plants that are expected to recover may die if hot dry conditions exist. Table 6-6, *Determining Yield Potential for Various Plant Stand Counts*, on page 186, indicates yield potential for various plant stand counts. The planting date will have an impact on the replant decision.

Seeding Rates

Historically, the seeding rates of cereal crops were recommended in bu/ac, with 2 bu/ac a standard that covered most cereal crops. Blanket statements of this nature are no longer acceptable. Seed size affects seeding rate. Optimum seeding rates should be set accordingly for each cereal crop. Table 6-7, *Recommended Plant Populations for Cereal Crops*, on page 186, gives the recommended seeding rates for each crop. Table 6-8, *Determining Seeding Rate*, on page 186,

Table 6–6.
Determining Yield Potential for Various Plant Stand Counts

Number of Plants		% Yield Potential	Planting Date	
			Yield: t/ha (bu/ac)	
per metre of row	per foot of row		Oct. 5	Oct. 15
66	20[1]	100	5.34 (80)	4.84 (72)
33	10	95	5.11 (76)	4.57 (68)
23	7	90[2]	4.84 (72)	4.37 (65)
20	6	85	4.57 (68)	4.10 (61)
16	5	80	4.30 (64)	3.90 (58)

Source: Smid, Ridgetown College, University of Guelph, 1986–90.

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[1] Full stand.

[2] 23 plants/m (7 plants/ft) of row, healthy and evenly distributed, will still achieve 90% of yield potential and does not require replanting. A field with an average of 23 plants/m (7 plants/ft) of row without relatively uniform distribution, or with plants severely damaged by heaving and other injury factors, will not yield satisfactorily. Consider replanting in this case.

indicates the seeds per metre of row and kilograms of seed per hectare required to achieve various desired plant populations.

In terms of seeding rates and desired plant populations, a variety with fewer seeds/kg will be at a disadvantage to a variety with more seeds/kg. To achieve the recommended rate for most soils, a higher seeding rate (kg/ha) will be required for varieties with few seeds/kg.

The higher rates in Table 6–7 and Table 6–8, right, should be used:

a) where emergence and early seedling establishment are likely to be poor (for example, due to poor seedbed and aerial or broadcast seedings)
b) for late planting where tillering will be reduced.

The seeding rate can be determined using this formula:

$$\text{Seeding rate (kg/ha)} = \frac{\text{seeds/ha}}{\text{seeds/kg}} \times \frac{100}{\text{\% germination}}$$

$$\text{Seeding rate (lb/ac)} = \frac{\text{seeds/ac}}{\text{seeds/lb}} \times \frac{100}{\text{\% germination}}$$

Table 6–7.
Recommended Plant Populations for Cereal Crops

	Target Plant Population		
Crop	Plants/m²	Seeds/ha (x1,000)	Seeds/ac (x1,000)
Barley	250–350	2,500–3,500	1,000–1,400
Oats	200–300	2,000–3,000	800–1,200
Mixed grain	200–350	2,000–3,500	800–1,400
Spring wheat	300–400	3,000–4,000	1,200–1,600
Winter wheat	350–450	3,500–4,500	1,400–1,800

Sample Calculation

Seeds/kg (seeds/lb) should be given on the seed tag or bag. For instance, if 3.7 million seeds/ha (1.5 million seeds/ac) is desired, with a germination rate of 95% and 26,500 seeds/kg (12,000 seeds/lb), the seeding rate should be 147 kg/ha (132 lb/ac).

$$\text{Metric:} \quad \frac{3{,}700{,}000}{26{,}500} \times \frac{100}{95} = 147 \text{ kg/ha}$$

$$\text{Imperial:} \quad \frac{1{,}500{,}000}{12{,}000} \times \frac{100}{95} = 132 \text{ lb/ac}$$

Table 6–8.
Determining Seeding Rate

	Desired Plant Population (seeds/ha) x 1,000					
	2,000	2,500	3,000	3,500	4,000	4,500
Row Width	**Seeds per Metre of Row**					
10 in.	49	62	75	89	102	112
8 in.	39	49	62	69	82	92
7.5 in.	39	46	56	66	75	85
7 in.	36	43	52	62	69	79
6 in.	30	39	46	52	59	69
4 in.	20	26	30	36	39	46
Seeds/kg	**Kilograms of Seed per Hectare**					
22,100	90	112	134	157	179	202
24,300	82	102	122	142	162	184
26,500	75	93	112	131	149	168
28,700	69	86	103	121	138	155
30,900	64	80	96	112	128	144
33,200	59	75	90	104	120	134
35,400	56	71	84	99	112	127
37,600	53	66	80	92	105	119
39,800	49	62	75	87	100	112
42,000	47	59	71	83	94	106
44,200	45	56	67	78	90	101

Table 6–9.
Winter Wheat Row Widths

	Winter Wheat Row Spacing				
	10 cm (4 in.)	18 cm (7 in.)	25 cm (10 in.)	36 cm (14 in.)	51 cm (20 in.)
Location	**Yield t/ha (bu/ac)**				
U.S					
Wisconsin 1985–87	6.32 (94)	6.32 (94)	5.44 (81)	–	–
Ohio	–	4.10 (61)	4.03 (60)	3.97 (59)	3.56 (53)
Canada					
Ontario[1]	5.38 (80)	5.38 (80)	–	–	–
On-Farm Trials					
Essex county	–	5.12 (76)	4.97 (74)	–	–
Middlesex county	–	5.98 (89)	5.91 (88)	–	

[1] Source: Smid, Ridgetown College, University of Guelph, 1987–90.

Row Widths

Considerable research has been conducted on cereal row widths for maximum yield. Table 6–9, *Winter Wheat Row Widths*, above, summarizes some winter wheat row width research from across Ontario and the northern U.S. On-farm results from Ontario are included in the table.

There is no evidence to support narrowing row widths below the standard 18–19 cm (7–7.5 in.) spacing for winter crops. There appears to be a yield penalty with wider rows. Many of the new 25-cm (10-in.) row planters have more accurate seed placement than most 19-cm (7.5-in.) drills. With the importance of seeding depth, this improved accuracy may partially overcome the row width impact, as indicated by the Essex, Middlesex and Ohio data, where accurate planting equipment was used for the 25-cm (10-in.) row widths.

For spring cereals, trials in Northern Ontario showed yield increases of more than 5% when row width was reduced from 18–10 cm (7–4 in.) spacing. Moving to 10-cm (4-in.) rows in this production area may prove beneficial. However, it is difficult to achieve these narrow row widths in a no-till system.

Additional Management Opportunities

Growers familiar with European cereal production are aware of the yield increases possible with the use of fungicides, growth regulators and increased fertility. Under Ontario conditions, it is more challenging to realize profits from incorporating these additional inputs within the production system. Experienced growers with high management capabilities in cereal production have developed the ability to use and profit from these strategies. Growers using this technology frequently benefit from increased yields associated with proper timing and use of these additional inputs. These growers are able to determine the best timing for application, if in fact application is warranted. Typically these growers achieve results well above average.

Foliar disease control is one of these management strategies. Further information on disease identification and control can be found in the section *Diseases*, on page 203, and in OMAFRA Publication 812, *Field Crop Protection Guide*. Thresholds for disease control vary, depending on the disease present in addition to the stage and condition of the crop. In general, it is important to scout the top two leaves of the cereal crop, at any stage of growth. If disease is moving onto one or both of these leaves, determine if the control threshold control has been reached and if control is warranted.

Growers who are proficient at cereal production realize yield increases well above the costs incurred by some of the newer fungicidal products on the market. A great deal of scouting and adjustment is necessary to optimize the return from using these more intense management tools.

Growth regulators are another management option to consider. Some cereal varieties have excellent yield potential but lodge prior to harvest, which reduces yield and quality. Growth regulators, when used at the proper application time and rate, can shorten and strengthen the straw and maintain standability until harvest of weaker strawed varieties. Stronger strawed varieties do not require this additional input. However, some growers feel that the increase in combine efficiency and speed of harvest of grain crops treated with a growth regulator justify treatment of all acres. Current research is continuing to determine if these benefits are real.

Table 6–10.
Nitrogen Requirements — Cereal Crops

Crop	N Required[1] kg/ha	(lb/ac)
Barley (areas receiving 2,600 CHUs or less)	70[2]	(63)
Barley (areas receiving more than 2,600 CHUs)	45	(40)
Cereals seeded as a nurse crop for forages	15	(14)
Mixed grain, spring triticale (S. Ontario)	45	(40)
Mixed grain, spring triticale (N. Ontario)	70	(63)
Oats, spring rye (S. Ontario)	35	(32)
Oats, spring rye (N. Ontario)[3]	55	(50)
Spring wheat[3]	70	(63)
Winter barley, winter rye	90[4]	(81)
Winter triticale	80[4]	(72)
Winter wheat	See Table 6–11, right.	

100 kg/ha = 90 lb/ac

[1] Where manure is applied or the preceding crop is a legume sod, reduce the nitrogen rates as shown in Table 2–15, *Adjustment of Nitrogen Requirement Where Crops Containing Legumes Are Plowed Down,* on page 36, and Table 2–16, *Average Amounts of Dry Matter, Nitrogen and Available Phosphate and Potash for Different Types of Organic Nutrient Sources,* on page 37.

[2] See the section *Nitrate-Nitrogen Soil Test and Spring Barley,* on page 189.

[3] Interim recommendation based on limited research.

[4] When not in rotation with tobacco.

Table 6–11.
Nitrogen Requirements for Pastry Wheat

Cost of Nitrogen Fertilizer $/kg	Expected Yield[1] t/ha 3.5	4.5	5.5
	Most Profitable Nitrogen Application[2] kg/ha		
.60[3]	75	85[4]	110
.70	70	85	105
.80	65	80	100
.90	60	75	95

100 kg/ha = 90 lbs/ac

For soft red or soft white pastry wheat. Based on winter wheat valued at $142/tonne. A maximum of 10 kg of nitrogen per hectare may be applied at seeding and the remainder top-dressed in early spring.

[1] Expected under your conditions of soil, climate and management.

[2] When not in rotation with tobacco.

[3] The most appropriate rate at time of printing.

[4] If your expected yield is 4.5 t/ha and nitrogen costs $.60/kg, the most profitable rate of application is 85 kg/ha of nitrogen.

Fertility

Fertilizers for Cereal Crops

Nitrogen

Cereals are members of the grass family and are very responsive to nitrogen. Over-application of nitrogen causes lodging in cereal crops, resulting in reduced yield, quality and difficulty in crop harvest (see Plate 101 on page 292). The optimum rate of nitrogen for a particular field will depend on the crop being grown, past applications of manure or fertilizer to the field, soil type and crop rotation. Use general recommendations as a starting point but combine them with observations of crop growth and lodging tendency.

General Recommendations

General nitrogen fertilizer recommendations for cereal crops are given in Table 6–10, *Nitrogen Requirements — Cereal Crops,* above, Table 6–11, *Nitrogen Requirements for Pastry Wheat,* right, and Table 6–12, *Nitrogen Recommendations for Spring Barley Based on Nitrate-Nitrogen Soil Tests,* on page 189. High rates of nitrogen from manure or manufactured fertilizers can cause lodging of cereals.

Recommendations for Hard Red Winter Wheats

The current recommended hard red winter wheat varieties are not true hard wheats. They are not equivalent to Canadian Western Red Spring wheat (CWRS) but are mid-strength varieties with bread-baking and other unique qualities. High protein content is required in these varieties to meet quality specifications. To achieve these protein levels, a higher rate of nitrogen fertilizer is often required. Limited field research would suggest that the optimum rate of nitrogen is 30–45 kg/ha (27–40 lb/ac) greater than for pastry (soft) wheat. There is some indication that splitting the nitrogen application between early spring and early stem elongation (Zadok's 31–32) can further increase protein, but this is rarely economical. Newer hard red varieties are being developed with inherently increased protein. These varieties may not require increased nitrogen to achieve protein levels that maximize protein premiums. Check with seed suppliers for advice on nitrogen rates for specific varieties.

Nitrogen for grain protein production is required later in the development of the plant than the nitrogen for yield. This makes hard wheat varieties ideally

Table 6–12. Nitrogen Recommendations for Spring Barley Based on Nitrate-Nitrogen Soil Tests

Spring Soil Nitrate-Nitrogen 0–30 cm (kg/ha)[1]	Price Ratio[2]			
	8	7	6	5
10	138	147	156	165
20	107	114	122	129
30	76	81	87	93
40	44	49	53	57
50	13	16	18	21
60	0	0	0	0

100 kg/ha = 90 lb/ac

For areas outside of Eastern Ontario that receive less than 2,800 CHUs.

[1] To convert to nitrate-nitrogen soil test (30-cm depth) from ppm to kg/ha, multiply by 4.

[2] The price ratio is the cost of the nitrogen in the fertilizer ($/kg N) divided by the selling price of the barley ($/kg of barley). See the section *Nitrogen/Corn Price Ratio,* on page 66.

suited to using the nitrogen from organic sources (legume plowdown or livestock manure). Desired protein levels are often easier to achieve on livestock farms due to these factors.

Nitrate-Nitrogen Soil Test and Spring Barley

The nitrate-nitrogen soil test can be used to predict nitrogen requirements for spring barley in areas other than Eastern Ontario that receive less than 2,800 CHUs (see Figure 3–1, *Crop Heat Units Available for Corn Production,* on page 57).

Since soils can vary greatly in their ability to supply nitrogen, the general recommendation found in Table 6–10, *Nitrogen Requirements — Cereal Crops,* on page 188, may not be the most profitable for some fields. The amount of nitrate-nitrogen present in the soil near planting time can be a useful indicator of a soil's ability to supply nitrogen. A recommendation based on a spring nitrate-nitrogen test should be considered as a guideline that is useful in formulating a nitrogen management program for spring barley (see Table 6–12, *Nitrogen Recommendations for Spring Barley Based on Nitrate-Nitrogen Soil Tests,* above).

Time and Depth of Sampling

Collect samples as close to planting time as practical (within 5 days of planting), allowing for sample shipping, analysis and receipt of results (contact the accredited lab to determine sample turnaround times). It is important that all cores in a field be taken to the same depth (30 cm). To ensure that the sample is representative of the field, take the same number of cores and use a sampling pattern similar to that recommended for the standard soil test under the section *Soil Sampling,* on page 29. See also Appendix L, *Diagnostic Service,* on page 267.

Table 6–13. Yield Loss Associated with Inaccurate Nitrogen Application Patterns

Yield t/ha (bu/ac)	
Low N	Full N
3.72 (55.3)	5.20 (77.3)

Source: P. Johnson, OMAFRA

Based on two locations in Middlesex County, 1998, three replications at each loction.

Where Caution Is Required

There are situations where the fertilizer recommendations based on nitrate-nitrogen soil tests should be adjusted. The nitrogen in manure or legumes applied or plowed down just before sampling will not have converted into nitrate and will not be detected by the soil test. Information will be provided with the soil test results on how to make appropriate adjustments.

Exercise caution if the recommendation is for large quantities of nitrogen and there is a history of barley lodging at lower rates of nitrogen. The nitrate-nitrogen soil test has not been adequately evaluated for:

1. legumes or manure plowed down in the late summer or fall
2. barley following legumes in a no-till system employing chemical burndown of the legumes

Uniformity of Nitrogen Fertilizer Application

To maximize yield, nitrogen must be applied uniformly across the field. Uniform application is more critical than the form of nitrogen fertilizer applied. Table 6–13, *Yield Loss Associated with Inaccurate Nitrogen Application Patterns,* above, shows the yield loss associated with inaccurate spread patterns. A 1.48 t/ha (22 bu/ac) yield difference was found between the fully fertilized and under-fertilized strips in the field.

Twenty-eight per cent nitrogen applied with streamer nozzles gives excellent, uniform nitrogen application. Urea or ammonium nitrate (calcium ammonium nitrate) can also be applied using airflow technology, although uniformity is not guaranteed. During humid days, urea can build up in the airflow tubes, restricting flow and affecting distribution. Be sure to maintain clear hoses to achieve a uniform spread pattern.

Table 6–14.
Yield Loss Associated With Leaf Burn From 28% Nitrogen Broadcast Treatment on Cereals

% Leaf Burn[1]	Yield	
	t/ha	bu/ac
5	4.97	74
7	4.70	70
8	4.64	69
13	4.50	67
21	4.50	67
27	4.03	60
	Least significant difference =7[2]	

Adapted from Jim Kells, Michigan State University, 1994.

[1] Seven days after treatment

[2] Least significant difference: 5% level

Spinner spreaders are not recommended for nitrogen application on cereals, due to the inconsistency of their spread pattern. If spinners are employed, consider double spreading the field (6-m or 20-ft centres at half the rate, instead of 12-m or 40-ft centres) to overcome this inconsistency.

UAN applied through streamer nozzles causes little or no leaf burn. Applying 28% nitrogen as an overall broadcast treatment (using flood jet or tee-jet nozzles) to emerged cereal crops is **NOT RECOMMENDED**. Table 6–14, *Yield Loss Associated With Leaf Burn From 28% Nitrogen Broadcast Treatment on Cereals*, above, shows the yield loss associated with this practice. The addition of 28% to a herbicide application, especially contact herbicides, will greatly increase leaf injury and yield loss (see Plate 102 on page 292).

Leaf Burn

Sometimes 28% leaf burn is credited with increasing tillering and a thicker, higher-yielding crop. In fact, visible leaf burn from a moving vehicle equates to at least 10% leaf damage. This level of damage would reduce the yield of an 5.71 t/ha (85 bu/ac) crop to only 5.38 t/ha (80 bu/ac). Twenty-eight per cent burn can be significant enough to kill underseeded red clover. Avoid leaf burn to increase yields.

Timing of Nitrogen Application

Most nitrogen fertilizers for spring cereals are applied before planting and worked into the soil. This allows optimum crop utilization of the fertilizer, while minimizing the risk of losses through run-off or volatilization. It is acceptable to top-dress emerged spring cereals, particularly if a starter fertilizer has been applied at planting.

Winter cereals should only receive a small application of nitrogen fertilizer at planting because of the risk of nitrogen loss overwinter. The majority of the nitrogen should be applied in early spring, just as the crop is beginning to green up. There is no consistent advantage to splitting the nitrogen applications on spring cereals or winter pastry wheat.

Phosphate and Potash

Phosphate and potash recommendations for cereals are given in Table 6–15, *Phosphate and Potash Recommendations for Cereals Based on OMAFRA-Accredited Soil Tests*, on page 191.

For information on the use of these tables or if you do not have an OMAFRA-accredited soil test, refer to the section *Fertilizer Recommendations*, on page 31.

Methods of Application

Where phosphate fertilizer is required for cereal crops, it is best drilled with the seed. Seed-placed fertilizers may include some or all of the required nitrogen and potash, depending on rates of application. For further information, see Table 2–30, *Maximum Safe Rates of Nutrients*, on page 47.

Plant Analysis

For cereals, sample the top two leaves at heading. Sample plants suspected of nutrient deficiency as soon as the problem appears. For plants less than 20 cm tall, sample the entire plant. For sampling at times other than heading, take samples from both deficient and healthy areas of the field for comparison purposes.

A soil sample should be taken from the same area and at the same time as a plant sample.

For more information, see Table 6–16, *Interpretation of Plant Analysis for Cereal Crops*, on page 192, as well as Appendix L, *Diagnostic Service*, on page 267.

Micronutrients

Manganese

Manganese deficiency frequently occurs when wheat, oats or barley are grown in an organic (muck) soil. It can occasionally occur in mineral soils high in organic matter and soil pH, and in very sandy soils. On oats, manganese deficiency appears as irregular oval grey spots on the leaves (see Plate 103 on page 292). On

Table 6-15.
Phosphate and Potash Recommendations for Cereals Based on OMAFRA-Accredited Soil Tests

	Spring Barley, Spring Wheat, Mixed Grain		Oats, Spring Triticale, Spring Rye		Winter Wheat, Winter Rye, Winter Barley, Winter Triticale		Winter or Spring Grains Seeded Down	
Sodium Bicarbonate Phosphorus Soil Test (ppm)	Rating	Phosphate (P_2O_5)[1] Required kg/ha	Rating	Phosphate (P_2O_5)[1] Required kg/ha	Rating	Phosphate (P_2O_5)[1] Required kg/ha	Rating	Phosphate (P_2O_5)[1] Required kg/ha
0-3	LOW	110	LOW	70	LOW	70	LOW	130
4-5		100		60		60		110
6-7		90		50		50		90
8-9		70		30		30		70
10-12	MEDIUM	50	MEDIUM	20	MEDIUM	20	MEDIUM	50
13-15		20		20		20		30
16-20		20	HIGH	0		20		20
21-25	HIGH	0		0	HIGH	0		20
26-30		0		0		0	HIGH	0
31-40	VERY HIGH	0	VERY HIGH	0		0		0
41-50		0		0	VERY HIGH	0	VERY HIGH	0
51-60		0		0		0		0
61 +	EXCESSIVE[2]	0	EXCESSIVE[2]	0	EXCESSIVE[2]	0	EXCESSIVE[2]	0
Ammonium Acetate Potassium Soil Test (ppm)	Rating	Potash (K_2O)[3] Required kg/ha	Rating	Potash (K_2O)[3] Required kg/ha	Rating	Potash (K_2O)[3] Required kg/ha	Rating	Potash (K_2O)[3] Required kg/ha
0-15	LOW	90	LOW	70	LOW	50	LOW	90
16-30		80		50		40		80
31-45		70		40		30		70
46-60		50		30		20		50
61-80		40	MEDIUM	20	MEDIUM	20		40
81-100	MEDIUM	30		20		20	MEDIUM	30
101-120		20	HIGH	0	HIGH	20		20
121-150		20	VERY HIGH	0	VERY HIGH	0		20
151-180	HIGH	0		0		0	HIGH	0
181-210	VERY HIGH	0		0		0	VERY HIGH	0
211-250		0		0		0		0
251 +	EXCESSIVE[4]	0	EXCESSIVE[4]	0	EXCESSIVE[4]	0	EXCESSIVE[4]	0

100 kg/ha = 90 lb/ac

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[1] Where manure is applied, reduce the fertilizer application according to the amount and quantity of manure (see the section *Manure*, on page 20). For spring barley in an area with less than 2,600 crop heat units, not manured and not following a legume sod, the nitrogen requirement is 70 kg/ha (see Table 6-10, *Nitrogen Requirements — Cereal Crops*, on page 188). If the soil test results are 11 for phosphate and 48 for potash, the phosphate requirement would be 50 kg/ha and the potash requirement 50 kg/ha. These nutrients could be supplied by drilling 250 kg (50 ÷ 20 x 100) of 5-20-20/ha to supply the phosphate and potash and broadcasting 170 kg of 34-0-0 or 130 kg of 45-0-0/ha to supply the recommended amount of nitrogen.

[2] A rating of "Excessive" may mean reduced yield or affected nutrient balance in crops and increased risk of nitrate movement into groundwater.

[3] Where manure is applied, reduce the fertilizer application according to the amount and quantity of manure (see the section *Manure*, on page 20).

[4] A rating of "Excessive" may mean reduced yield or quality of crops primarily due to magnesium deficiency. Natural levels above 250 occur occasionally on clay and clay loam soils but are not expected to cause problems because soils naturally high in potassium are usually high in magnesium.

Table 6–16.
Interpretation of Plant Analysis for Cereal Crops

Nutrient	Units	Critical Concentration[1]	Maximum Normal Concentration[2]
Nitrogen (N)	%	2.0	2.7
Phosphorus (P)	%	0.1	0.5
Potassium (K)	%	1.0	3.0
Calcium (Ca)	%	–	1.0
Magnesium (Mg)	%	0.15	1.0
Boron (B)	ppm	3.0	40.0
Copper (Cu)	ppm	3.0	50.0
Manganese (Mn)	ppm	15.0	200.0
Zinc (Zn)	ppm	10.0	70.0

Values apply to the top two leaves sampled at heading.

[1] Yield loss due to nutrient deficiency is expected with nutrient concentrations at or below the critical concentration.

[2] Maximum normal concentrations are more than adequate but do not necessarily cause toxicities

barley and wheat, it appears more commonly as a light yellow colour on the leaves with the veins in the leaf remaining slightly darker green (see Plate 104 on page 292). Both soil tests and plant analyses are useful in predicting where manganese deficiencies are likely to occur. Both analyses are available at the OMAFRA-accredited soil testing laboratories.

Correct the deficiency as soon as detected by spraying the foliage with 2 kg manganese/ha from manganese sulphate (8 kg manganese sulphate/ha) in 200 L of water. Use a "spreader-sticker" in the spray. If the deficiency is severe, a second spray may be beneficial. Winter cereals growing in areas of severe manganese deficiency may require an application in the fall to insure winter survival.

Soil application is not recommended, regardless of source, because of the large amounts of manganese that would be required. In most cases, deficiencies in the plants are caused by a low availability of manganese from the soil rather than a lack of manganese. Adding more manganese to the soil will not often correct this.

Copper

Copper deficiency may occur in organic (muck) soils and is suspected on rare occasions in very sandy soils. The most common deficiency symptom is dieback from the tip of the leaf, often accompanied by twisting of the upper leaves. For information on correcting copper deficiencies, see the section on *Micronutrient Fertilizers*, on page 34.

Boron

Boron deficiency has not been diagnosed in cereals. Boron applications can be toxic, causing a bleaching of leaf tissue in seedlings.

Zinc

Zinc deficiency in cereals does not appear to be a problem.

Mixtures of herbicides and foliar fertilizers should not be applied to crop foliage unless recommended by competent authorities. Always consult the herbicide label.

Harvest and Storage

Optimizing Combine Adjustments

Operator manuals contain the best starting point for setting up a small grain harvest. Occasionally, conditions arise that require further adjustments. Harvest of *Fusarium*-damaged grain, lodged crops or crops infected with dwarf or common bunt require special attention. The easiest and best way to improve the grain sample in these situations is with proper combine adjustment. Often the difference between a marketable crop and sample grade wheat is in the combine set-up. Don't be afraid to experiment.

Storage of the crop allows the opportunity to upgrade the grain before delivery to an elevator or mill. This is particularly important for wheat infested with any of the bunt diseases. Many producers have experimented with re-cleaning the grain through screen cleaners, seed cleaners and fanning mills to upgrade the crop to a better sample. Elevator operators can also do this, for a fee. This can have tremendous economic benefit, where grain can be moved from salvage grade to milling grade. Upgrading the grain makes it much easier for the elevator to handle the crop and find a purchaser for the grain.

Fusarium-Damaged Grain

Combines use air blast to separate grain from the chaff in a normal harvest operation. Many of the *Fusarium*-infected kernels are small, shrunken and lighter than sound kernels. It is often possible to blow a large proportion of these *Fusarium*-damaged kernels out the back of the combine by increasing the air blast above normal ranges. In 1996, many producers operated combines at the maximum windblast to increase

Table 6–17.
Effect of Different Fan-Speeds on Wheat Yield

	Fan Speed (rpm)							
	1,160	1,190	1,220	1,250	1,280	1,320	1,330	1,330
	Sieve Setting: 6 mm ($^1/_4$ in.)							Front Closed
Good kernels on ground: per m^2 (per ft^2)	172 (16)	125 (11.6)	340 (31.6)	263 (24.4)	379 (35.2)	446 (41.4)	470 (43.6)	461 (42.8)
Loss: t/ha (bu/ac)	0.06 (0.83)	0.04 (0.58)	0.11 (1.58)	0.08 (1.22)	0.12 (1.76)	0.14 (2.07)	0.15 (2.18)	0.14 (2.14)
Loss at 4.03 t (60 bu) yield: %	1.38	0.97	2.63	2.03	2.93	3.45	3.63	3.56

Case International 1644, Harus Wheat, Essex County, July 17,1996. Travel speed 6.8 km/h (4.2 mph). Rotor speed 880 rpm.

Source: Dr. Art Schaafsma, University of Guelph, Ridgetown College, 1996.

grade. Research conducted by Dr. Art Schaafsma (University of Guelph, Ridgetown College) in 1996 found a tenfold decrease in *Fusarium*-damaged kernels in the grain when fan speeds were operated at maximum blast (up to 300 rpm above book settings). Operating cleaning fans at these levels causes an additional loss of good kernels, up to 0.13 t/ha (2 bu/ac) (see Table 6-17, *Effect of Different Fan-Speeds on Wheat Yield*, above). This small yield reduction is insignificant if the crop can be made marketable, rather than being downgraded to feed, sample or salvage.

Harvest should not begin above 16% moisture if significant *Fusarium* is present. High moistures reduce the ability to blow outer lighter *Fusarium*-damaged kernels.

Slowing the forward ground speed of the combine may further reduce *Fusarium* levels. This allows increased separation of the grain mass, giving the increased windblast time to separate the good kernels from the infected kernels. Consider adjusting the cleaning sieves (chaffer) to a more wide-open setting. This directs the air blast vertically, slowing rearward movement of the grain mass and aiding cleaning and separation. Caution must be used to keep heads and straw particles out of the grain sample if the chaffer is opened.

Unfortunately, there will be times that the grain cannot be raised to milling standards. If this occurs, consider putting as much of the damaged grain as possible in the bin, if a suitable market for the damaged grain can be found.

Consider storing the *Fusarium*-damaged crop. Often, as harvest finishes, the pressure eases on those involved in handling the crop. Marketers and millers are able to assess the markets that do exist and the best way to condition wheat to fit that market.

Remember that wheat going into storage must be dry (14% moisture or below). Damp wheat allows the *Fusarium* to continue to grow and produce toxins, further downgrading the crop. Check stored grain frequently to ensure that the grain stays in condition.

Lodged Grain Crops

There are several effective options for harvesting lodged grain crops.

Grain Lifters

Setting up a combine for lodged wheat takes extra time and care while in the field. Although flexible cutter bars on floating soybean heads are standard on combines today, consider using grain lifters, which lift the crop above the cutter bar. This is an inexpensive way of maximizing yields.

Knife Adjustment

On floating cutter bars, leave the knife tilted down and run the header in the float position as if harvesting a soybean crop. Take care not to feed rocks into the combine if choosing this option.

Reel Adjustment

Adjust the reel on the combine. Most reels are permanently on the best setting for soybean harvest (newer combines have hydraulic adjustment from the cab), but this setting is not appropriate for a lodged cereal crop. Set the reel forward and adjust the tine angle to be more aggressive, allowing the reel to physically lift the crop up off the ground and above the knife. Check the operator's manual for suggested settings and fine tune from there.

Harvesting Direction

The last option, an unfortunate reality in some years, is to harvest the grain in one direction.

Bunt-Infected Wheat

By far the easiest way to avoid being forced into harvesting a bunt-infected crop is to use properly treated seed. However, when bunt does infect the crop, harvest and storage must focus on minimizing bunt balls in the sample and reducing the "fishy" odour following harvest.

Do not harvest bunt-infected crops at high moisture. Spores from broken bunt balls adhere more easily to damp grain. Harvest dry grain using slow cylinder speeds and open concave clearance to minimize the number of bunt balls broken during the harvest process. Operate cleaning fans at high speed to blow as many of the bunt balls and bunt spores out the back of the combine as possible.

Storage of bunt-infected wheat is an effective way to upgrade the grain. Aeration is the key. Store bunt-infected grain in storage facilities with lots of aeration capability. Aerate the grain until the odour has disappeared. Take care when removing the grain from storage, as the handling process can break remaining intact bunt balls and re-contaminate the grain. Belt conveyors are preferable to augers when moving bunt-infected grain. Use of aspiration during the handling process will often lift out remaining bunt balls and keep the grain in condition.

Never contaminate or attempt to blend bunt-infected wheat with clean wheat. It takes very little bunt to downgrade the grain. Blending will simply contaminate the good grain, not improve the damaged grain.

For more information, see the section *Dwarf Bunt and Common Bunt (Wheat)*, on page 207.

Drying and Storing Wheat

Winter wheat is sometimes harvested at a high moisture content because of wet weather or to reduce harvest losses. Wheat is considered dry at 14.5% moisture.

Winter wheat must be dried to 13%–14% moisture content for safe storage.

Table 6–18.
Recommended Airflow for Natural-Air and Low-Temperature Wheat Drying

Moisture Content (% wet basis)	Minimum Airflow	
	L/sec/m^3	CFM[1]/bu
16	6.5	0.5
17	9.75	0.75
18	13	1.0

Adapted from Wilcke, William F., Hellevang, Kenneth J. *Wheat and Barley Drying*. FS-5949-GO, 1992. University of Minnesota, Extension Service.

[1] CFM = cubic feet per minute.

Drying Systems

Three different systems can be used to dry wheat:

1. natural-air drying bin
2. low-temperature dryers (less than 40°C or 104°F)
3. high-temperature or high-speed dryers (temperatures greater than 40°C or 104°F)

Natural-Air and Low-Temperature Drying

Natural air drying of wheat will only occur when the relative humidity of the outside air is below the equilibrium moisture content of the grain. The effectiveness of natural air drying systems is greatly reduced during rainy periods and at night when temperatures are cool and humidity levels are normally high. When air temperatures fall below 10°C (50°F), forced ambient air will not pick up as much moisture, and supplemental heat may be required. Extended periods of humid weather may also need additional heat. Raising the temperature of the incoming air by 5°C (41°F) degrees will dry the air but should not overdry the grain at the bottom of the bin. Recommended airflow for natural-air and low-temperature wheat drying is displayed in Table 6–18, *Recommended Airflow for Natural-Air and Low-Temperature Wheat Drying*, above.

Minimum requirements for natural-air drying:

- Full aeration floor in the bin
- Level grain surface across the entire bin
- Minimum airflow of 6.5 L/sec/m^3 (0.5 CFM/bu), preferably more
- Clean wheat with no weed seeds or fines
- Accurate moisture reading of the wheat in the bin
- Accurate outside air temperature and relative humidity measurement
- An understanding of wheat equilibrium moisture content
- An on/off switch for the fan

Table 6-19. Maximum Recommended Air Temperatures for Drying Milling Wheat[1]

Dryer Type or End Use	Maximum Temperature	
	°C	°F
Non-recirculating batch dryers	60	140
Recirculating batch dryers	60-70	140-158
Cross-flow continuous dryers	60	140
Parallel-flow dryers	70	158
Seed wheat	40[2]	104

[1] Copyright: *Farm Drying of Wheat*, Canadian Grain Commission, Sept 1992.

[2] Wilcke, William F., Hellevang, Kenneth J. *Wheat and Barley Drying*. FS-5949-GO, 1992. University of Minnesota, Extension Service.

A full aeration floor is essential to move air uniformly through the entire bin contents. With a partial aeration floor or air duct system, dead areas will exist, leading to potential spoilage problems. Weed seeds, green trash and fines accumulations in the bin will restrict or divert airflow. Air moving through the wheat mass will take the path of least resistance.

High-Temperature Drying

With high-temperature drying, large volumes of heated air, 40°C (104°F) or higher, are used to accomplish drying in a few hours or days. Corn dryers could be used but it may be necessary to reduce the drying temperature to avoid loss of starch quality and germination. It is important not to exceed the recommended maximum air temperatures for drying milling wheat (see Table 6-19, *Maximum Recommended Air Temperatures for Drying Milling Wheat*, above), which are dependent on the type of dryer used and the end use of the wheat.

> For safe drying, the temperature of grain kernels should never exceed 60°C (140°F).

The baking quality of wheat is damaged if the temperature of the grain reaches 60°C (140°F) for any significant length of time. When heated air dryers are used, it is a worthwhile precaution to have samples evaluated to ensure the dried grain meets market standards.

Tough wheat can be dried with natural air under good drying conditions. Natural-air drying of wheat requires careful management by the operator since wheat gives up and takes on moisture easily. Only run the fan when outside conditions will result in drying progress.

> Do not run the fan continuously, night and day, as the wheat will re-wet at night. The progress you make during the day will be undone during the night.

Determining Airflow

Sufficient airflow is needed to move drying air through the entire wheat mass. To remove moisture, the minimum airflow required is 6.5 L/sec/m^3 (0.5 CFM/bu); anything less will only change the temperature but not the moisture content of the wheat. Higher airflow rates of 26 L/sec/m^3 (2 CFM/bu) or greater only speeds the drying process. These higher airflow rates may be difficult to achieve with much higher fan horsepower required. The small kernel size of wheat causes the spaces between the kernels to be small. Moving large amounts of air through deep beds of wheat will take a large fan with high static pressure capability. If this bin and fan combination is capable of supplying 26 L/sec/m^3 (2 CFM/bu) when filled with corn, only fill it one-half to one-third that depth with wheat. With axial flow fans, filling the bin to one-third the depth of corn is a good starting point.

To determine the CFM/bu value for a bin, determine the number of bushels in the bin and the static pressure that the fan is operating against. A simple manometer connected to the air plenum below the perforated floor will show the static pressure (inches of water displaced in the column). Refer to Appendix I, *Home-Built Manometer*, on page 265, for a diagram of a homemade manometer. Using the fan performance curve, the fan output at the measured static pressure can be determined.

> To calculate CFM/bu airflow, divide the CFM output of the fan by the number of bushels in the bin (1 CFM/bu = 13 L/sec/m^3).

If adequate airflow cannot be achieved, one strategy is to partially fill the bin. In this way, the fan will be operating at less static pressure and will deliver higher airflow rates per bushel.

Equilibrium Moisture Content

Researchers have developed equilibrium moisture content tables (see Table 6-20, *Equilibrium Moisture Content for Soft Winter Wheat Exposed to Air*, on page 196) that allow the prediction of the final mois-

Table 6–20.
Equilibrium Moisture Content for Soft Winter Wheat Exposed to Air

Temperature °C (°F)	Relative Humidity %				
	50	60	70	80	90
0 (32)	12.5	13.5	14.6	16.1	18.2
5 (41)	12.1	13.1	14.2	15.7	17.9
10 (50)	11.7	12.7	13.9	15.3	17.5
15 (59)	11.4	12.4	13.5	15.0	17.2
20 (68)	11.1	12.1	13.2	14.7	17.0
25 (77)	10.8	11.8	13.0	14.4	16.7

ture content of winter wheat when exposed to air with a certain temperature and relative humidity.

For example, you can find the equilibrium moisture content of wheat exposed to outside air at 25°C (77°F) and 80% relative humidity. In Table 6–19, *Maximum Recommended Air Temperatures for Drying Milling Wheat*, on page 195, find the point at which the 25°C (77°F) line and the 80% relative humidity line intersect. This point will be the equilibrium moisture content for wheat at the outside air conditions stated. Given enough time, the wheat will dry down to 14.4% moisture content.

When to Run the Fan

Air temperature and relative humidity levels should determine fan operation, not the time of day. On some days, drying can be accomplished from 9:00 a.m. until midnight, while on others it may only be from 9:00 a.m. to 6:00 p.m. Check the temperature and relative humidity of the air frequently throughout the day. As the wheat loses moisture, drier outside air is needed to continue to make drying progress. If the equilibrium moisture content on a given day is less than the moisture content of the wettest wheat, drying is possible and the fan should be on. Install a humidistat that will activate the fan at preset humidity levels. The operator can adjust the relative humidity level at which the fan is activated.

The wheat at the top of the bin will be the last to dry. Each day of fan operation will push a drying front up through the bin. This drying front may not reach the top of the bin that same day. Be sure to take moisture samples at the same depth each time to know how the moisture content is changing at that depth. Bins with stirrators will have fairly uniform moisture levels throughout the entire bin as a result of the mixing that has been done.

Table 6–21.
Impact of Weeds on Cereal Crop Yields

Crop	Weed	Weedy Plants/m^2	% Yield Loss
Spring barley	Wild oats	13	5%
Spring barley	Green foxtail	175	5%
Spring wheat	Wild oats	8	5%
Spring wheat	Wild oats	25	14%
Spring wheat	Green foxtail	100	5%

Adapted from *The Manitoba/Saskatchewan Guide to Crop Protection*, 2001.

Weed Control

Critical Period for Weed Control

There are no critical periods for weed control established for cereal crops. Control weeds early in the growth of the cereal crop. Beyond the five-leaf stage of the cereal crop weeds can be more difficult to control, and the crop is more susceptible to herbicide injury. When winter annual weeds are a problem in winter cereals, spray them before the weed's flowering stage to improve control.

The product label for postemergence herbicides indicates the growth stage of the weeds when optimum control can be obtained. Time weed control for the optimum growth stage of the weed, and as early as possible.

Crop Losses Due to Weeds

Yield losses will vary with the weed species and weed density, as well as the timing of weed emergence and control. Later-emerging plants tend to be less competitive and produce fewer seeds per plant. Cereals, especially winter varieties, are more competitive with weeds than row crops such as corn or soybeans.

Table 6–21, *Impact of Weeds on Cereal Crop Yields*, above, is based on research from Western Canada and shows the impact of wild oats and green foxtail in spring wheat and barley. Yield losses assume the weeds emerge with the crop. Crop losses are less when the weeds emerge after the crop. Note that wild oats are more competitive than green foxtail and that barley is more competitive with weeds than spring wheat.

Studies in Ontario have shown that annual broadleaf weeds are more competitive than annual grasses (see Table 3–26, *Percent Corn Yield Loss Due to Weeds at Known Populations*, on page 74, and Table 4–17, *Soy-*

bean Yield Loss Due to Weeds at Known Populations, on page 115).

Consider crop quality when making weed control decisions. Infestations of wild oats in a cereal crop can have serious consequences to market quality because of the presence of this weed seed in the harvested crop.

Mechanical Weed Control

Blind harrowing with a light harrow, before emergence of cereals, can help control small germinating weeds. Use a light harrow in cereals up to the three-leaf stage, or a weeder harrow (L-shaped flexible tines) at the four-leaf stage to provide better control of small annual broadleaf weeds. The timing of these harrowing operations is critical. The weeds must be small and the soil surface dry and easily worked to achieve success.

Integrated Weed Management

Weed control in the cereal crop is influenced by:

- crop rotation
- plant population
- row width
- variety characteristics
- tillage practices

In general, the agronomic practices that produce a healthy, fast-growing crop will allow it to compete well with weeds.

The early-season harvest of cereal crops creates an opportunity to improve weed control in the field during the late summer. Weeds that are left to grow following harvest can result in a high weed seed return to the soil seed bank, creating weed problems in following crops. Weeds should not be left to grow following harvest when they can reach maturity and produce seed. Control practices following cereal harvest for annual weeds will be done earlier than for perennial weeds such as quackgrass from which seed production is minimal.

Crop rotations can be effective in reducing certain perennial weeds that may grow best in a particular crop. Use vigorous, high-quality seed to achieve uniform stands at the recommended plant populations to compete with the weeds. Early planting gives the crop a head start on the weeds to assist with crop competition. Planting deep can delay emergence and favour weed development.

Equipment can spread weed seeds from one field to another. Combines, tillage equipment and soil erosion can all transport weeds. Weeds can also infest a field from manure application or other soil amendments. Proper sanitation and cleaning of equipment along with maintenance of field border areas all affect the long-term weed management in a field.

Refer to OMAFRA Publication 75, *Guide to Weed Control*, for more information, including herbicide products and rates.

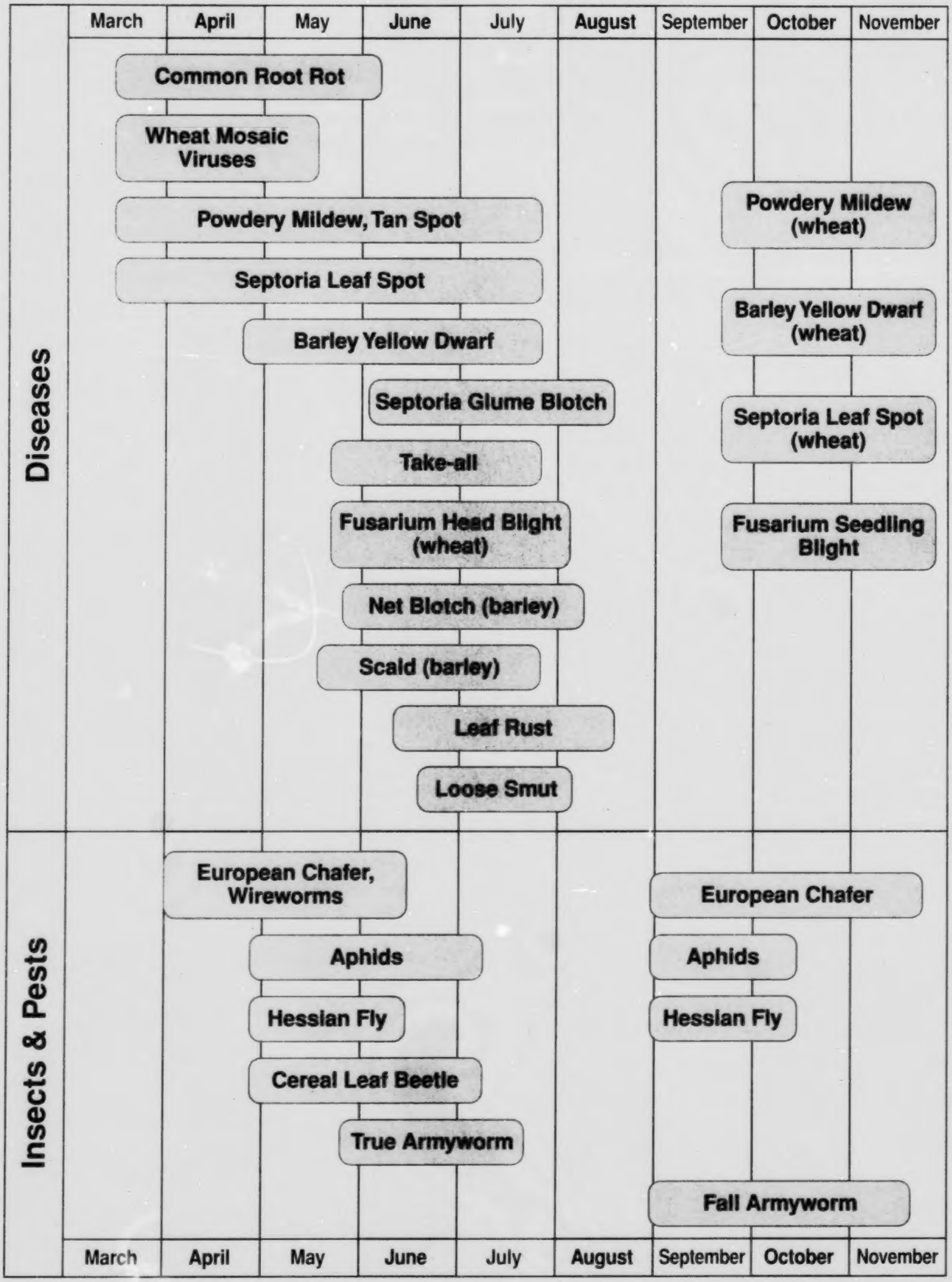

FIGURE 6–3.
Cereal Crops Scouting Calendar

Insects

Table 6–22, *Symptoms in the Field,* below, shows insects and pests that may be causing the symptoms in the field.

Individual descriptions of insects found in cereals and recommendations for their control follow.

Table 6–22.
Symptoms in the Field

Symptom	Possible Insects and Pests						
	Armyworm (true)	Armyworm (fall)	Cereal aphid	Cereal leaf beetle	European chafer	Hessian fly	Wireworm
Gaps in the stand					x		x
Plants stunted or lodged (field may appear blue)						x	
Bronze patch in field			x				
Leaf feeding:							
Scratches running parallel with leaf veins				x			
Ragged holes in leaves	x	x					
Head clipping	x						

Wireworm

Description: Wireworms are slender, cylindrical, hard-bodied insect larvae reaching up to 4 cm (1½ in.) in size. They are usually copper-brown but when newly moulted they can be soft-bodied and white (see Plate 9 on page 275). Adult wireworms are beetles that have the ability to flip themselves upright when placed on their backs, making an audible click as they do, giving them their name "click beetles."

Life History: Wireworms take up to 6 years to develop from egg to adult, spending most of their life as larvae. They overwinter as larvae in the soil below the frost line. When soil temperatures warm in the spring, the larvae move to the surface to feed. Due to their long life cycle, the larvae can damage several successive crops, feeding on the roots of weeds, grasses and crop plants. Once soil temperatures become hot and soil moisture decreases, the larvae migrate downward and may be difficult to find later in the season. When it is time to become adults, the larvae migrate back to the surface and pupate, and the adult emerges to mate and lay eggs in grasslands or weedy areas.

Damage: Wireworms are most active during the months of April through June and occur most often in fields that have little disturbance. The larvae attack roots, seeds and germinating seedlings of many crops such as corn, soybeans, wheat, edible beans and potatoes. Non-uniform growth or gaps in the stand may be due to wireworm feeding on germinating seeds. Wireworms are rarely a problem in fall-planted cereals, however, they can be serious in spring-planted grains. They are also generally more prevalent in sandier soils, especially on the knolls.

Scouting Technique: Wireworms should be scouted in mid-April, prior to planting. To scout for wireworms, a few weeks before planting, establish two bait stations per high-action site in each field. Dig a hole at each station, approximately 15 cm wide and 5–8 cm deep. Choose one or two high-action sites in the field, such as sandy knolls or heavy grass infestations. Bury a nylon mesh bag with 1 cup equal parts untreated and soaked corn and wheat or freshly cut potatoes at the bottom of the station. Mound the soil over the bait to prevent standing water. Return to the stations a few days before planting to sift through the bag contents to record the number of larvae found per station.

Action Threshold: One wireworm per bait station.

Management Strategies: Seed treatments should be used in fields with a high wireworm incidence or following grassy sods. Seed treatments will protect germinating seed but tend not to protect the seedlings. No rescue treatments are available. For insecticide recommendations, see OMAFRA Publication 812, *Field Crop Protection Guide.*

European Chafer (White Grub)

Description: European chafer larvae are white and C-shaped with an orange-brown head and dark posterior. This pest can be distinguished from other white grubs by its Y-shaped pattern of anal bristles known as "rasters" located on the underside of the last abdominal segment of the larva (see Plate 10 on page 275). The adult is a medium-sized, light brown, fawn-coloured, oval scarab beetle, closely resembling the native May or June beetle.

Life History: This pest overwinters as larvae or "grubs" in the soil below the frost line. In April to mid-May, these larvae migrate close to the soil surface and feed on plant roots. Larvae then pupate in mid-May to mid-June, and adult beetles emerge from the soil in early June to early July to mate. Adult chafers congregate in conspicuous mating flights and can be seen swarming at dusk. The beetles fly to tall objects along the horizon, usually trees or other landscape to mate. The adult females then locate cool, moist soil in nearby fields or lawns to lay their eggs in. Eggs hatch and newly hatched larvae begin feeding on roots in late July until the ground freezes. The grubs then migrate down, below the frost line, to overwinter. There is one generation per year.

Damage: Damage is mostly done by the larvae stage, however, adults may feed on plant leaves. European chafers tend to feed earlier in the spring and longer in the fall than other white grub species.

Chafer grubs feed on the fibrous roots of grasses, forages, winter grains, corn, soybeans and lawns, $1^1/_2$–5 cm (1–2 in.) from the soil surface. Larvae feed on and prune roots, causing plants to become stunted and wilted. If the plants are larger and actively growing, damage, as in the case of soybeans, may not be apparent. Intense root feeding results in poor emergence and stunted plants.

Scouting Technique: It is best to scout for chafers in the fall in standing soybean stubble. Scout for chafers on the sandier knolls of the field. Using a shovel, dig up approximately 1 ft of soil, about 3–4 in. deep, for five single soybean plants in each area sampled.

Action Thresholds: No thresholds are available at this time. Avoid planting winter cereals if chafer grubs are easily found.

Management Strategies: Avoid replanting with corn if chafer grub population is extreme. Cultural options include disturbing the soil by tillage or disking, which brings the grubs to the surface where they are exposed to the elements and natural enemies such as birds, skunks, racoons, etc.

Cereal Aphid

Description: Also known as the bird cherry-oat aphid, this aphid is small (2 mm or less), dull olive-green, with patches of red-orange near the rear of the abdomen, between a pair of tubes called cornicles (see Plate 105 on page 292). The cornicles and legs are pale green, and the antenna is long and black. Younger aphids are a light green. Like all aphids, they are soft-bodied, winged or wingless, with piercing and sucking mouthparts that suck the juices (nutrients) from young plant tissues. Aphids secrete a sticky substance referred to as "honeydew," which can cause sooty mould.

Do not confuse this aphid with the corn leaf aphid. The corn leaf aphid is more rectangular, while the cereal aphid is bulb-shaped.

Life History: Cereal aphids do not overwinter in Ontario but migrate in as winged females from the Southern United States.

Damage: Seldom a direct problem in Ontario. On young plants, aphids cluster on the upper sides of the leaves near the base of the plant. Eventually, aphids will climb to the top and can be found in the leaf whorls. High populations can cause a field to appear to have a large bronze patch. They are a vector for barley yellow dwarf virus. See the section *Barley Yellow Dwarf Virus*, on page 206.

Scouting Technique: For direct aphid damage, scout the field weekly prior to heading. Examine 20 stems in five areas across the field. Shake the plants over a piece of paper and count the number of aphids present. Also make note of any predators present and whether the aphids are parasitized or infected with a fungus.

Action Thresholds: Twelve to fifteen cereal aphids per stem prior to the heading stage, and up to 50 aphids per head once headed.

Management Strategies: Spray early when action threshold has been reached. (See OMAFRA Publication 812, *Field Crop Protection Guide,* for recommended insecticides). To avoid barley yellow dwarf virus in winter cereals, avoid planting too early. Plant after fly-free planting dates set for your region (Refer to the section *Planting Dates*, on page 183). Kill volunteer wheat 2–3 weeks before planting. Several natural enemies feed on aphids, including ladybird beetle larvae, syrphid fly larvae and lacewing larvae.

Hessian Fly

Description: Adult Hessian flies resemble small mosquitoes. They are smoky grey and fragile, and have pointed abdomens. The abdomen of the female fly is reddish, which is caused by the colour of the eggs developing inside. Adults are weak flyers and only live about 3 days.

Life History: Two generations occur per year. The Hessian fly overwinters as "flax seed" puparia in the base of old plant crowns. Adults emerge in the spring. Females lay their long, reddish eggs in rows on the upper surface of leaves of young winter wheat or volunteer wheat. Larvae develop and feed for approximately 3 weeks before forming a puparium in mid-June. A second generation emerges, and the insect continues its cycle until late September when it forms a puparium for overwintering.

Damage: Occurs both in the spring and fall. Larvae feed between the stem and leaf sheaths of the plant, causing the plant to turn dark bluish-green. Plants will become stunted and tough and eventually lodge. Heads may become bleached in colour. Risk factors include early-planted wheat and susceptible varieties.

Scouting Technique: In the spring, scout fields when heads begin to fill. In the fall, begin scouting 3 weeks after wheat plants have emerged. Examine 20 plants in five locations across the field. Look for the "flax seed" puparia to determine the percentage of infestation.

Action Threshold: None available.

Management Strategies: Delay planting of winter cereals until after the fly-free date. Refer to the section *Planting Dates*, on page 183 for optimum seeding dates for your region. Destroy volunteer wheat and stubble before planting. Resistant varieties are available. No rescue treatments are available.

Cereal Leaf Beetle

Description: The cereal leaf beetle (CLB) adult is a metallic, blue-green beetle, approximately 0.5 cm in length, with a reddish-orange head and legs. The larvae are 0.6 cm in length when mature and yellowish in colour, but this colour is obscured by a black deposit of fecal material making it slug-like in appearance (see Plate 106 on page 292).

Life History: CLBs overwinter as adults in leaf litter in sheltered areas such as woodlots and heavy crop debris. These adults emerge in early spring, and the mated females then lay their eggs in wheat fields on the upper surface of the leaves. The eggs hatch, and larvae are present by mid-May. The larvae will pupate, and adults will emerge by mid-June. Adults feed on wheat briefly and then congregate in corn fields, feeding for a short period before going dormant until fall. In the fall, adults become active again and make their way to their overwintering sites. There is one generation per year.

Damage: Cereal leaf beetles feed on wheat, oats, corn, forages and grassy weeds. Both adults and larvae cause damage by chewing long strips of tissue between the leaf veins, leaving the top layer of the leaf intact. This creates a window-paning or "skeletonizing" effect. Most of the injury is caused by the larvae in June. Heavily damaged fields appear silver.

Scouting Technique: Begin scouting in late April. Examine 20 plants in five locations across the field. It is important to scout various areas of the field, as CLB tends to be unevenly distributed across the field. Record the number of beetles and larvae found per plant. Scout every 5 days, as damage can increase dramatically within days.

Action Threshold: One CLB adult or larvae per stem warrants control, especially in the earlier stages of the crop (before heading).

Management Strategies: An insecticide may be necessary when the threshold has been reached. See OMAFRA Publication 812, *Field Crop Protection Guide*, for insecticide recommendations. This pest is mainly controlled by natural enemies where reduced tillage is practised. Clean plowing increases the risk of this pest, because the overwintering sites of the parasites are destroyed. In some parts of Ontario with mild winters or tobacco production (where plowing is practised), the parasites have been less effective.

True Armyworm

Description: When full grown, true armyworms are 4-cm (1½-in.) long, dull green-to-brown larvae (see Plate 107 on page 293) that can be easily confused with other caterpillars, including variegated cutworm and fall armyworm. Two distinguishing features that true armyworm possess are white-bordered stripes running laterally along the body and dark diagonal bands at the top of each abdominal proleg. The head is yellow-brown with a network of dark brown lines creating a pattern. The sand-coloured adult moth has distinctive white spots on the centre of each forewing.

Life History: In early spring, the moths prefer to lay their eggs in grassy vegetation. Larvae hatch from the eggs and feed at night or on overcast days for approximately a month. There are two generations per year, but it is the first generation that tends to do the most damage in corn in Ontario.

Damage: Most feeding damage is done on cereals during June. Feeding first begins on the leaves, but larvae will also move up and feed on the awns and tender kernels. Head clipping can also occur. When crops are heavily damaged, armyworms will migrate to nearby crops.

Scouting Technique: Begin scouting in early May. Examine plants from five locations in your field to determine the level of infestation. In spring cereals, focus attention on the edge of the field near grassy weeds where the eggs may have been laid. Winter cereals can be as attractive to moths as grassy weed borders so the field may be infested anywhere. During the day, look for true armyworms under the crop residue and soil clods. Record the size and number of larvae. When scouting, check the backs of armyworms for eggs. These small, oval, yellowish eggs are usually located just behind the head of the larva. These are eggs of a parasitic fly. The eggs will hatch, and the maggots will kill the armyworm larvae.

Action Threshold: Four unparasitized larvae, smaller than 4 cm (1½ in.), per square foot, if head clipping is occurring.

Management Strategies: If the larvae are almost full grown (about 4 cm or 1½ in. long), there is no benefit in applying insecticide since most of the feeding damage has already been done. Insecticides will only be effective on larvae that are less than 4 cm or 1½ in. long. Refer to OMAFRA Publication 812, *Field Crop Protection Guide,* for insecticide recommendations. Treatment may be confined to infested areas. The parasites and other beneficial organisms usually keep armyworms from reaching damaging levels. Avoid treating with insecticides when large numbers of parasitized larvae are present.

Fall Armyworm

Description: Full-grown fall armyworms are 4 cm (1½ in.) long, varying in colour from light tan or green to near-black (see Plate 19 on page 277). Three white, thin strips run down the back with one thicker, yellow band with red spots running along the side, just above the legs of the larvae. The fall armyworm larvae has a white inverted "Y" on the front of the head, while the true armyworm does not. The fall armyworm head is dark brown.

Life History: Fall armyworm adult moths migrate from the southern states and show up later in the season when the corn is fully grown. This insect cannot overwinter in areas where the ground freezes.

Damage: Fall armyworms attack seedling wheat in the fall from September until frost. Fall armyworm feeding occurs in the daytime, unlike true armyworm feeding, which occurs at night. Initial leaf feeding appears as ragged-edged holes and moist, reddish-brown frass can be found nearby.

Scouting Technique: Examine 20 plants from five locations in your field to determine the level of infestation. Record the size and number of larvae. When scouting, check the backs of armyworms for parasite eggs. These small, oval, yellowish eggs are usually located just behind the head of the larva. These are eggs of a parasitic fly whose maggots will kill the armyworm larvae.

Action Threshold: Two to three unparasitized larvae, less than 4 cm (1½ in.) in length, per square foot.

Management Strategies: Fall armyworm populations are rarely common in winter cereals. If the action threshold is reached, a spray may be necessary. See OMAFRA Publication 812, *Field Crop Protection Guide,* for insecticide recommendations.

Diseases

Seedling Diseases: Seed Rot, Seedling Blight and Root Rots

Organisms that colonize seed and soil are responsible for many of the most damaging diseases in cereal crops. These organisms are responsible for early-season seed rots and seedling blights as well as the smut (bunt) diseases of the grain (see Plate 108 on page 293).

Disease management of these organisms begins with the use of good-quality, clean seed. All wheat seed needs to have a fungicide seed treatment applied to control soil-borne and seed-borne diseases, such as seed rots and seedling blights, seed-borne *Septoria,* seed-borne Fusarium seedling blight, seed-borne dwarf bunt, common bunt and loose smut. The best protection against seedling blights, smut and the bunts can be achieved through the use of a seed treatment that contains a combination of fungicides, since no one fungicide is effective against all these diseases. Good coverage of the seed is essential, since seed treatment performance may be reduced. Significant yield losses continue to occur from these diseases in fields where fungicide seed treatments have not been used.

Fusarium Seedling Blight (Crown Rot)

Incidence: Fusarium seedling blight can be carried on seed or in crop debris. Poor stand establishment, non-uniform emergence, "gaps" or missing plants are primary symptoms of seed or seedling infection (from planting to several weeks after emergence). There are several different species of *Fusarium* that cause the disease (*F. culmorum, F. graminearum* and *F. avenaceum*). *Fusarium culmorum* is the most destructive to older plants while *F. avenaceum* and *F. graminearum* are more damaging to seedlings.

Appearance: Seed rots or seedlings are killed before emergence. Seedlings that do emerge are stunted and yellow, with the crown, roots or lower stem having a brown to red-brown rot. Brown or reddish streaks may occur on the stem. Lesions are variable in shape and size and do not have distinct margins. The disease may occur on older plants as well, causing a reduction in the number or size of tillers that mature prematurely with white and shrivelled heads. Plant vigour is reduced in infected plants.

Disease Cycle: These fungi infect many cereals, grasses and other plants, including corn. They survive in seed, in crop residue and in soil. During the fall, they grow from these sources into the crown, roots or leaf sheaths. At this stage, they can cause seed decay and seedling blight. In spring, the lesions continue to expand so that crown rot, stem rot and root rot develop. Moist soil in the fall favours infection of the plant, but dry soil and high levels of nitrogen fertilizer favour the progress of the disease in the spring. The fungi, especially *F. graminearum,* also infect heads and contaminate seed (see the OMAFRA Factsheet, *Head Diseases of Winter Wheat,* Order No. 83-032, or visit the Web site at www.gov.on.ca/OMAFRA/english/crops. The disease is likely to be more severe on wheat that follows wheat, barley or corn.

Management Strategies: Delay planting until conditions will result in a rapid and uniform emergence. Avoid planting after corn and maintain a balanced fertility program. Fungicide seed treatments are very effective against seed-borne and soil-borne organisms that cause this disease. Refer to OMAFRA Publication 812, *Field Crop Protection Guide,* for more information on seed treatments. Other options include the use of tolerant varieties and planting disease-free seed. Use wheat in at least a 3-year crop rotation since these organisms can survive in wheat residues. Avoid planting wheat after corn.

Pythium Root Rot

Incidence: Pythium root rot damage on wheat is common in Ontario and is one of the primary seedling diseases of small grains. There are several species of *Pythium* that attack small grains and, although *Pythium* is present in all soil types, losses are greatest in cold, wet, clay soils. *Pythium* (like *Phytophthora*) is a "water mould" that thrives under wet, saturated conditions and therefore, infection is very dependent on soil moisture and the clay content of the soil. The wetter the soil and the higher the clay content, the greater the potential for infection. *Pythium* produces mobile spores that migrate through the water film in the soil.

Appearance: Although infection occurs in the embryo 1 or 2 days after planting, seedlings are rarely killed.

Infected plants appear stunted with small, pale green-to-yellowish leaves; this is often incorrectly identified as a nutrient deficiency. These symptoms often go unnoticed until spring when non-infected plants begin to grow rapidly. Infected roots are light brown with few or no root hairs. Infection begins at the root tips and disintegrates root hairs and the fine lateral roots, which are critical for nutrient uptake. Affected plants often occur in patches with a general unhealthy appearance. Severely infected plants may break at the soil line.

Disease Cycle: The fungi survive in the soil and crop residues. They produce spores (zoospores) that swim through moisture films on soil particles and invade the wheat roots. Some species are most damaging in warm soils, while others prefer cold soils. The disease is less severe when phosphate levels are adequate for good root growth.

Management Strategies: Minimize soil compaction and remove excess moisture through increased drainage. Seed treatments containing metalaxyl or metalaxyl-M can reduce infection. Delay planting until conditions will result in a rapid and uniform emergence. For more information on fungicides, refer to OMAFRA Publication 812, *Field Crop Protection Guide.*

Take-All

Incidence: There are two closely related fungi that cause take-all in Ontario. The first infects wheat, barley, rye and various grasses, whereas the second is a problem on oats and turfgrasses.

Appearance: Take-all usually becomes noticeable at the heading stage when the heads, stems and leaves of badly affected plants become prematurely bleached (see Plate 109 on page 293). The bleaching of tillers takes only 2 or 3 days. Affected plants occur in circular patches, one to several metres across, or as individuals or small clusters scattered across the field. Many plants appear moderately to severely stunted and bear few tillers. The bleached heads (whiteheads or deadheads) normally are sterile and usually appear 3–5 weeks before harvest. Whiteheads may also be caused by factors other than take-all. Dark-coloured moulds tend to grow on the whiteheads, especially in damp weather. The conspicuous bleaching is secondary to disease on the roots, crown and lower stem.

The roots of diseased plants are sparse, blackened and brittle. The dark-coloured rot often extends to the crown and basal stem. Removal of the lowest leaf sheath reveals a dark shiny layer of fungal material on the stem that is easily scraped off. Weakened stems lean or lodge in various directions as in eyespot. In many instances, the disease is confined to the roots, and no symptoms appear on the crowns, stems and heads. The wheat take-all fungus produces spores (ascospores) inside tiny black structures (perithecia) on the sheath of the lower leaf and on stubble residues at the soil surface.

Disease Cycle: The main source of the fungus is infested crop residues in the soil. The fungus survives best in the residues when the soil nitrogen content is high. Brown strands (hyphae) of the fungus grow from the residues, through the soil and over the surface of the roots, crowns and stems. The fungus spreads from plant to plant by means of "root bridges." Using a hand lens, it is often possible to see the brown strands on the roots while the roots remain whitish. The roots turn black after the fungus penetrates into them. Invaded crowns and stems develop a brownish, dry rot.

The severity of take-all generally increases as soil alkalinity increases (pH rises) and fertility (especially nitrogen and phosphorus) decreases. Wet soil, especially in spring and early summer, is highly favourable to the disease. Soil compaction aggravates take-all. Cool weather (12°C–18°C) is more favourable than warm weather. The disease is more severe when wheat is sown early than when sown near the end of September or in October. When wheat is grown continually on the same land, take-all becomes increasingly severe during the first 3–5 years, but subsequently declines. Take-all predisposes wheat to drought stress, especially in June and July.

Management Strategies: Carefully manage soil fertility. Neutral to alkaline and infertile soils are most at risk. Do not apply lime before planting. Soils deficient in potassium and phosphorous cause plants to be more susceptible because of poor root development. Nitrate nitrogen increases disease severity. Control grasses and avoid early planting. Use a 3-year crop rotation and avoid planting wheat after wheat.

Eyespot (Strawbreaker) Rhizoctonia Sharp Eyespot

Incidence: The fungi that cause these diseases can be found in most of Ontario soils and have the ability to cause disease in many crops. These diseases become a problem in fields or regions that predominantly grow cereal crops under cool, moist conditions.

Appearance: Eyespot and sharp eyespot produce lesions on the lower sheaths and stems of most cereals (see Plate 110 on page 293). Winter wheat is more susceptible than spring cereals. In the spring, both diseases produce elliptical, eye-shaped lesions on the lower internodes near the soil line. Lesions have a dark brown border with a tan or straw-coloured centre.

Distinguishing between the two diseases is difficult. Rhizoctonia sharp eyespot lesions are more superficial and their margins are sharply defined; plants infected with eyespot (strawbreaker) have a white fungal growth in the lower stem cavity. In severe cases, plants infected with these diseases may lodge, bend or break at the soil line from a weakening of the stem at the lesion areas. Other symptoms include reduced yields, whiteheads and death of tillers.

Disease Cycle: The eyespot fungus survives in the residue of infected plants for 3 or more years and is most severe under cool, wet conditions. The sharp eyespot fungus survives in the soil and on infected crop residues. Sharp eyespot is most severe in light, dry, acidic soils during cool springs. Dry conditions in the fall and spring favour development of sharp eyespot.

Management Strategies: Avoid planting cereals 2 years in a row, preferably leaving at least 2 years between cereal crops. Practices that bury stubble in the soil are effective in reducing eyespot severity. Eyespot can be severe when the stubble remains on the surface. Sharp eyespot can be severe when crops are planted early and deep. Fungicide seed treatments may reduce losses (refer to OMAFRA Publication 812, *Field Crop Protection Guide*).

Snow Moulds

Incidence: Although snow moulds do require specific environmental conditions, they occur most years to some degree. Severity increases in years when an early snow cover in the fall (mid-November) persists until late March or April.

Appearance: Snow mould symptoms appear soon after snow melt. Individual plants, groups of plants or large areas can be affected. The most obvious symptom is dead plants that are slimy, brown and rotted (see Plate 111 on page 293). Early-planted wheat is usually affected since lush "top-growth" promotes infection and aids in disease spread from plant to plant. Plants that have not been killed (i.e., have a healthy crown) may have one or many leaves that are totally or partly necrotic (i.e., have brown tips). Symptoms are most pronounced in areas of the field that had heavy snow cover, such as field borders, headlands and down slopes of hills. Typical winter injury on wheat due to other causes will most often occur in areas that had no snow or were covered in ice. Symptoms are pronounced in fields planted with poor-quality or untreated seed. Warm, dry weather in the spring will stop disease development and promote rapid plant growth. Plants with considerable damage often recover from the disease with little or no impact on yield.

Disease Cycle: The group of fungi that cause snow moulds are temperature tolerant and will grow under heavy snow cover. Snow deeper than 30 cm will insulate the soil, preventing it from freezing while maintaining a soil surface temperature at or just above 0°C (32°F). Under these conditions, photosynthesis is significantly reduced, and the developing wheat plant has no choice but to use its stored carbohydrates and proteins to survive. The result is a stressed plant that is more susceptible to diseases, especially snow moulds.

Management Strategies: Although no winter wheat cultivars are resistant to the disease, they do differ in tolerance. Seed treatments are very effective against snow moulds but they must be applied on the seed and good seed coverage is essential. In years when snow mould causes substantial reductions in stands, replant to a spring grain or soybean crop. The disease does not affect spring-planted grain.

Leaf and Stem Rust

Incidence: There are various species of rust that cause disease on wheat and barley. Leaf and stem rust occur in all regions of Ontario every year. Stem rust may be a serious problem when small grains are grown near the common barberry bush. Of the two rust diseases, leaf rust continues to pose the biggest threat to small grain production.

Appearance: Leaf rust affects the leaf blades and sheath, whereas stem rust can be found on leaves, sheaths, stem and heads. The disease begins as small, yellow-brown spots (pustules) that contain orange-to-orange-brown spores (see Plate 112 on page 293). In most cases, infection is found on the upper surfaces of the leaves and leaf sheath. In severe cases, leaves turn yellow and brown (necrotic). In spring grains, late-planted fields are most likely to show the disease, whereas late-maturing winter wheat may be slightly more at risk.

Stem rust begins as dark reddish-brown spots on both sides of the leaves, stems and heads (see Plate 113 on page 294). When developed, spots will rupture through the surface releasing spores into the air. The surface of the tissue appears ragged and torn.

Disease Cycle: Common barberry is necessary for the stem rust fungus to complete its lifecycle. Leaf rust, on the other hand, does not overwinter in the province but is blown into Ontario on southerly storm fronts from infected plants in the Southern United States and Mexico wheat regions. In most years, leaf rust spores arrive late (after flowering), resulting in little economic impact. These diseases are most severe when warm temperatures (20°C–28°C or 68°F–82°F in day, 16°C–22°C or 61°F–72°F at night) and frequent dews occur when the crop is at the flag leaf (Zadok's 37) to flowering (Zadok's 61–71) stages.

Management Strategies: Removing the alternate host, common barberry, will reduce stem rust. Use tolerant varieties when possible. Since leaf rust usually appears on the upper two leaves first, it is important when scouting for rust to check the second leaf from the top prior to head emergence, and the flag leaf during head emergence for signs of disease. Use foliar fungicide treatments when the flag leaf has 5–10 pustules or 1% of the flag leaf area is affected (during head emergence to the end of flowering) and the weather forecast predicts rainy, wet weather. Planting spring grains early allows plants to mature before inoculum levels become heavy. In oats, crown (leaf) rust is dependent on European buckthorn as the alternate host. Remove or destroy buckthorn. Refer to the OMAFRA Publication 812, *Field Crop Protection Guide*, for fungicide treatment recommendations.

Barley Yellow Dwarf Virus

Incidence: Barley yellow dwarf virus (BYDV) has been called the most widely distributed and most destructive virus disease of cereals. It has been found in Canada, the U.S., Europe, Australia, Asia, New Zealand, Africa and South America. BYDV attacks a wide range of grass hosts, including wheat, oats and barley. Of these, oats are considered the most susceptible.

Appearance: The primary symptoms are stunting and yellowing, reddening or purpling of the leaf tips (see Plate 114 and Plate 115 on page 294). Barley yellow dwarf virus is often confused with other virus diseases (spindle streak mosaic virus, soil-borne mosaic virus — see Table 6–23, *Comparison of BYDV, SBWMV and WSSMV*, on page 207), nutrient deficiency or environmental causes. Identifying viral pathogens is very difficult and requires accurate serological tests. It is best to send samples to a diagnostic lab with these capabilities.

Disease Cycle: Barley yellow dwarf virus is transmitted by aphids only. Several species of aphids have been identified as vectors for BYDV, including the greenbug, the corn leaf aphid, the English grain aphid and the bird cherry-oat aphid. Damage occurs as a result of aphid feeding, since aphids feed directly on a plant's sap and therefore reduce the nutrients available for plant growth. The contact with the plant sap makes aphids ideal vectors for BYDV. It is usually found in patches 1–2 m in diameter but can occur uniformly throughout the field if aphid populations are also uniform throughout the field. Yield losses are very dependent on the crop stage when infected. Generally, losses are greater when infection occurs on young seedlings in the fall (>30%) rather than in the spring.

Management Strategies: Few control options are available. The best strategy is to avoid early planting. Early planting allows the aphids more time to infect the plants in the fall. Recommended or optimum planting dates for winter wheat take into consideration barley yellow dwarf virus and Hessian fly and promote a vigorous plant to maximize winter hardiness (see the section *Planting Dates*, on page 183). Planting earlier during mild or late autumns allows

Table 6–23.
Comparison of BYDV, SBWMV and WSSMV

Virus	Transmission	Major Symptoms	Additional Hosts
Barley yellow dwarf virus	Aphids	General chlorosis, reddening, purpling, stunting	Barley, oats, corn, sorghum, millet, grasses
Soil-borne wheat mosaic virus	Soil-borne fungus (*Polymyxa graminis*)	Yellow-green mosaic, stunting, rosetting	Rye, barley, grasses, sorghum
Wheat spindle streak mosaic virus	Soil-borne fungus (*Polymyxa graminis*)	Green-yellow mosaic, streaks, spindles	Rye, barley

the aphids to survive longer than usual. Early seeding is an advantage in spring grains. Chemical sprays to control the aphid vectors are not practical or economical, since scouting or detecting the aphids is very difficult. By the time populations reach detectable levels, virus transmission has most likely already occurred. Preventative sprays would not be economic as BYDV is unpredictable.

Soil-Borne Wheat Mosaic Virus (SBWMV)
Wheat Spindle Streak Mosaic Virus (WSSMV)

Incidence: These two viruses are often easily confused with each other since the symptoms, life cycle and field pattern are similar. In certain cases, both viruses may be present in the same field.

Appearance: Typical symptoms of SBWMV on wheat leaves is a mosaic of green islands or blotches on a yellow background. Typical leaf symptoms of wheat spindle streak are yellow-to-light green streaks that are parallel to the leaf veins. The streaks are often tapered, which gives the lesions a spindle shape, hence the name. This is in contrast to soil-borne mosaic virus lesions, which are blotches. WSSMV can also cause stunting and reduced tillering in infected plants.

Disease Cycle: It is not uncommon to find that many plants are infected with both viruses since they share a common vector. The common link is a soil-borne fungus called *Polymyxa graminis*. The fungus produces zoospores (swimming spores) that invade root hairs and epidermal cells of young plants during periods of high soil moisture or in low, wet areas of the field. The virus is carried into the plant by the zoospores. The fungus can remain in the soil for at least 8 years. It is not as important to determine which of the two viruses is present as it is to determine that the symptoms are not due to other causes (fungal, bacterial, etc.). The first report of spindle streak mosaic in North America occurred in 1957, right here in Ontario. Fields at risk are those that have had several crops of winter wheat in the past 8–10 years. Yield losses range from less than 5% to 40%, but generally losses are low. Symptoms usually appear early in the spring when growth resumes. The optimum temperature for symptom development is 5°C–15°C (41°F–49°F).

Management Strategies: Since the fungal vector for both viruses can survive for many years in the soil, crop rotation as a management option has had limited success. Fields that have had liberal amounts of poultry and livestock manures appear to reduce wheat spindle streak mosaic virus build-up.

Dwarf Bunt and Common Bunt (Wheat)

Incidence: Common bunt (stinking or covered smut) occurs anywhere in Canada where both spring and winter wheat is grown. This is in contrast to dwarf bunt where the disease has only been reported in two provinces — British Columbia and Ontario. In Ontario, dwarf bunt primarily occurs in the counties bordering Georgian Bay and Lake Huron where snow cover is deep and persistent in late winter and early spring. In severe years, some fields have had over 50% bunt.

Appearance: In Canada, there are three fungal species that can cause bunt in winter wheat. The first two are *Tilletia tritici* and *Tilletia laevis*, which cause common bunt or covered smut. The third is *Tilletia controversa*, which causes dwarf bunt in winter wheat. The main symptom of all three of these pathogens is the production of "bunt balls," which replace healthy kernels. These bunt balls contain masses of black powdery fungal spores called teliospores. When infected grain is harvested or crushed, these bunt balls rupture easily, releasing their spore contents, resulting in contamination of the grain. Besides the bunt balls, one of the most obvious signs of these diseases is the pungent, fishy odour of the spores. The odour is important, since the disease has quarantine significance: many importing countries have zero tolerance for bunt-contaminated wheat shipments. Often the spore cloud and the distinctive odour are the first signs that a crop may have the disease.

Common bunt and dwarf bunt are hard to distinguish between and often require microscopic examination. One difference is that the bunt balls of common bunt are similar in shape and size to the kernels they have replaced. Whereas, for dwarf bunt, the bunt balls are smaller and tend to be rounder. Plants infected with dwarf bunt are dramatically shorter (half as tall as healthy plants) whereas plants infected with common bunt suffer only a slight reduction in height. A fourth bunt fungus causes Karnal bunt or partial bunt. Fortunately, this disease has not been found and does not occur in Canada.

Disease Cycle: Dwarf bunt and common bunt can infect winter wheat plants either through the seed (seed-borne) or from the soil (soil-borne). Although common bunt can be soil-borne, the fungus appears to be primarily a seed-borne disease and can be effectively controlled with currently registered seed treatments. Dwarf bunt is harder to control, since spores of the fungus can survive for 10 years or more in the soil.

Management Strategies: Start by planting seed that is free of bunt spores. Do not keep seed if you have any bunt present. Some registered seed treatments are more effective than others. Refer to OMAFRA Publication 812, *Field Crop Protection Guide,* for more details.

Management Tips

1) Cut high with the combine.

Wheat infected with dwarf bunt will be substantially shorter than healthy plants. Raising the header will reduce the amount of bunt balls harvested.

2) Harvest below 15%.

Bunt balls and spores that are dry tend to be sent out of the combine easier. The wetter the grain, the more likely bunt spores will adhere to it. Removing wet spore balls through the combine is very difficult since they are very heavy.

3) Combine wind-blast set at maximum.

Turning the wind-blast settings up will remove a large portion of the bunt balls. Minimal good grain will be lost at maximum wind.

4) Harvest fence rows and bush areas separately.

Infection will be most severe where snow was the deepest and stayed the longest. Harvesting the majority of the field separately should minimize the number of bunt balls in the sample.

5) Clean grain before storage.

It is important to remove as many bunt balls from the sample before storage as possible. Bunt balls will rupture during handling or removing from the bin. Bunt balls are similar in size to wild buckwheat seed. Therefore, screens that remove wild buckwheat should remove many of the bunt balls in the sample.

6) Put grain into the bin with full aeration.

It will take an extended period of aeration to remove the odour from the sample.

Loose Smut

Incidence: Loose smut has traditionally been one of the most destructive diseases of wheat and barley in Ontario. The development and use of fungicidal seed treatments have managed the disease very effectively. Unfortunately, some producers continue to plant untreated, infected wheat seed, and losses of 10%–30% have been observed in these fields.

Appearance: Kernels are replaced by dry, black masses of spores, visible soon after heads emerge (see Plate 116 on page 294). Over time, all that remains is the naked spike. Infected plants appear normal until heading time.

Disease Cycle: The fungus that causes the disease survives in infected wheat seed and subsequently infects the developing plant. The fungus grows throughout the plant, eventually infecting the head and replacing the grain. Spores are spread by wind and infect adjacent plants. Infected seed appears normal and cannot be separated out. Wheat and barley are the main hosts, whereas oats and rye are quite tolerant.

Management Strategies: Sow pedigree seed that has been treated with seed protectant that contains a systemic fungicide. Refer to OMAFRA Publication 812, *Field Crop Protection Guide.*

Ergot

Incidence: Ergot occurs from time to time on barley, wheat and triticale. Although yield loss in most cases is insignificant, the impact of the disease on grain quality and marketability can be significant since ergot bodies are toxic to livestock and humans. Exercise caution in feeding grain containing the black ergot bodies to livestock, especially swine. Outbreaks in Ontario are infrequent and sporadic, but ergot can be severe in some fields that have been damaged by frost, herbicide, etc., that resulted in sterile heads. Sterile florets tend to remain open and thus more prone to infection.

Appearance: The first sign of this fungal disease is often the brown-to-purplish-black sclerotia ("ergot bodies") protruding from the spikelets of the head. These ergot bodies replace the kernels and can be up to 1 cm in length.

Disease Cycle: The fungus survives the winter as sclerotia in the soil and on seed. From here, spores are released that infect the florets and with the aid of insects are transferred to other spikes. Rainy, wet and cool weather that prolongs flowering increases the likelihood of infection. Ergot "sclerotia" are well adapted and can survive for many years in the soil.

Management Strategies: Use clean seed and do not plant seed containing ergots. Allow a minimum of 1 year between other susceptible crops (rye, wheat, barley, triticale).

Powdery Mildew

Incidence: Powdery mildew is a common plant disease that can cause damage when present in wheat and barley fields. Wheat cultivars will vary in their susceptibility to the disease. The yield impact of powdery mildew infections is hard to predict. The disease robs the plant of nutrients and reduces the photosynthetic ability of the leaf. Yield losses are generally minimal from early infections unless the weather remains cool and humid. Mildew infections that attack the flag leaf and the second leaf are more serious. The health of the top two leaves determines the kernel size, test weight and yield. Losses due to powdery mildew have been stated anywhere from 2%–30% of total yield. Very rarely in Ontario have losses been greater than 10%–15%.

Appearance: The characteristic symptom of the disease is the production of a fluffy white-to-grey fungal growth that often begins on the lower leaves (see Plate 117 on page 294). Infection can move rapidly up the plant on leaves, sheaths, stems and heads under favourable conditions. Leaves develop elongated yellow streaks or areas that may turn brown and die prematurely. Severely diseased plants may lodge or result in poor grain fill. Older, light-grey areas of fungal growth often have small black spots. The white-to-light grey fungal growth is most noticeable in the early morning while the plants are still wet. The infection is superficial, and the fungal growth can be easily removed with your fingers or a knife.

Disease Cycle: The fungus survives on crop residues, such as straw or stubble, fall-planted winter wheat seedlings, volunteer cereals and wheat. Spores that are released are primarily spread by the wind. The spores require near 100% relative humidity and temperatures between 15°C and 21°C (59°F and 70°F). A dense stand and vigorously growing crop can lead to poor leaf-drying conditions which are favourable conditions for powdery mildew. The disease is very susceptible to weather conditions that promote drying of the crop environment such as hot, dry, sunny weather. Powdery mildew also thrives in fields where high rates of nitrogen have been used. Nitrogen not only increases tiller formation, causing dense stands, but also increases the susceptibility of the crop. Watch for mildew in fields that have had more than 78 kg N/ha (70 lb N/ac). Powdery mildew growth stops when temperatures are above 25°C (77°F).

Management Strategies: In most cases, powdery mildew has little impact on rye or oats since these crops are very resistant to the disease. In areas prone to severe mildew, use resistant (tolerant) winter wheat varieties. Removal of crop residue through tillage in conjunction with a crop rotation that limits wheat or other susceptible cereals from being planted in the field for a minimum of 2 years may lower disease risk. Foliar fungicide applications are necessary when disease levels will result in yield losses. Thresholds for fungicide applications differ depending on the age of the crop. Early-season powdery mildew control is warranted when 5%–10% of the lower leaves are infected, which may limit later infection. Later in the season, powdery mildew symptoms on the flag leaf (1% of leaf) and the second leaf (3%–5% of the leaf) require immediate attention, especially if prolonged wet, humid weather is forecast. Refer to OMAFRA Publication 812, *Field Crop Protection Guide*, for further information on fungicide products.

Septoria Leaf Spot
Stagonospora (Septoria) Glume Blotch

Incidence: Septoria leaf spot and Stagnospora (Septoria) glume blotch are two diseases that are caused by different species of *Septoria*. Both diseases are common in Ontario and of economic importance. They attack most small grains and many grasses, but wheat is the only important commercial host.

Appearance: Septoria leaf spot attacks only leaves, whereas Stagonospora glume blotch appears on the leaves and glumes. Initial infections from Septoria leaf spot appear as small, light green-to-yellow spots between the veins of the lower leaves (see Plate 118 on page 295). These spots elongate to form irregular reddish-brown lesions. Embedded in these lesions are small, dark brown-to-black fungal bodies (pycnidia) that can be seen easily with the use of a hand lens.

Stagonospora glume blotch develops after the heads emerge and is favoured in warm, humid conditions. Small, oval, irregular, grey-to-brown spots appear on the leaves and purplish-brown areas on the glumes (see Plate 119 on page 295). The affected areas are also speckled with small black pycnidia. The presence of pycnidia is an important diagnostic feature that aids in distinguishing Septoria leaf spot and Stagonospora glume blotch from other leaf spot diseases.

Disease Cycle: Septoria fungi survive on seed, straw, stubble or volunteer wheat and are favoured by wet or humid conditions, and moderate temperatures. Along with powdery mildew, leaf diseases caused by *Septoria* are often the first that occur in the spring since they thrive under cool, humid, wet conditions. Although both fungi are limited by hot weather, *Stagonospora* can tolerate somewhat higher temperatures than *Septoria*. Prolonged wet periods in May and early June result in increased disease incidence. The leaf phases of both diseases characteristically move from infected lower leaves upward (secondary disease cycles). The glume stage of Stagonospora glume blotch, on the other hand, does not move vertically within the canopy but quickly across the field, infecting only the heads.

Management Strategies: Rotation with crops other than cereals, plowing down cereal residues and removing volunteer wheat will reduce the survivability of these fungi. Unfortunately, in most years, spore levels are sufficient to cause disease under favourable environmental conditions. Balanced fertility programs are important since high rates of fertilizer and early planting may result in dense foliage going into the winter, thus increasing disease levels. Septoria leaf spot may develop under snow cover in winter wheat. Use good quality seed that has been treated with a fungicide seed treatment to prevent seed-borne infection. Current varieties have limited tolerance. Foliar fungicides provide effective control of Septoria leaf spot and Stagonospora glume blotch. Application thresholds vary, depending on wheat-growth stage. Applications are justified when one to two lesions (1% of the leaf area) are found on the leaf below the flag leaf up to the boot stage, or when one to two lesions (1% of the leaf area) are found on the flag leaf at head emergence (flowering). For fungicide information, refer to OMAFRA Publication 812, *Field Crop Protection Guide*.

Fusarium Head Blight (Scab)

Incidence: Fusarium head blight (scab) is one of the most important diseases of small grains in Ontario. In recent years, severe outbreaks have occurred when the weather is warm and wet at the flowering to soft dough stages. Besides the potential for significant yield losses, mycotoxins that are harmful to livestock can be produced.

Appearance: Symptoms of scab become noticeable soon after flowering. Diseased spikelets (glumes and florets) appear to have ripened prematurely (bleached) in contrast to healthy, green heads. The fungus may attack all or only part of the head. Bleaching of the heads or head blight appears 3–5 days after infection. The entire head may be killed when the neck (the stem immediately below the head) is infected (see Plate 120 on page 295). During warm, humid weather, the fungus produces a salmon-orange-to-pink ring of spores at the base of the spikelet or in the crease of the kernel. If conditions continue, the infection may spread to adjacent kernels. Infected kernels are usually shrunken, wrinkled and light in weight. These kernels have a rough, scabby appearance and range in colour from light brown to pink to greyish-white. The amount of scab on the seed depends on the time of infection and the weather conditions at the time of infection.

The planting of infected seed can result in the development of the seedling blight phase of the disease, which is separate from scab. Infected kernels may not germinate and can result in poor stands. Infected plants that emerge may lack vigour and will often die before they become established. Infected seedlings can appear light-to-reddish-brown and may be covered with a white or pink mould. As the plants mature, they are usually smaller with few tillers and small heads. If the root or crown is cut, a light-to-reddish-brown root rot can be observed.

Disease Cycle: Although several species of *Fusarium* can cause scab, the principal pathogen is *Fusarium graminearum*, which can infect corn, wheat, barley, oats and rye. All species overwinter in infected kernels, chaff, stubble or straw/stalk residues left on the soil surface. They survive between crops as asexual spores (conidia), fungal strands (mycelium) and within dark purplish-black fruiting bodies (perithecia), which the sexual spores (ascospores) are borne in. The fungi will continue to grow and produce spores from harvest until the crop residues have decomposed in the soil.

Both types of spores can be carried from infected residues of the previous crop by wind or rain splash onto the wheat head. The conidia are produced during warm, moist weather on corn and small grain residues while the ascospores are released during wet and dry cycles. By doing so, the fungus is able to spread spores into the air for a longer period of time. Spores that land on the head require rainfall or heavy dew to germinate and invade flower parts (anthers), glumes and other portions of the head. The potential for disease increases substantially when these spores land during an extended warm period at temperatures between 22°C–27°C (70°F–80°F) with wet, humid weather. The longer it stays wet during flowering, the greater the chance of infection and therefore increased disease severity. If warm, moist weather continues, the salmon-pink spore masses produced on the spikelets will be air-borne and can act as another source of infection.

Management Strategies: Avoid planting wheat following wheat or corn. When residues of either of these crops are left on the surface and wheat is subsequently planted, the chances of Fusarium head blight infections are greatly increased. Clean plowing of infected residues reduces the risk of infection from spores originating from within the field. However, Fusarium head blight may still develop from spores blown in from surrounding fields under weather conditions favourable to disease development. As many of the infected kernels are small, shrunken and lighter than sound kernels, it is possible to blow a large proportion of these kernels out the back of the combine by increasing the air blast above normal ranges. This may cause some additional loss of good kernels (up to 0.13 t/ha or 3 bu/ac). Proper storage and drying will limit further Fusarium head blight development after harvest. The availability of resistant varieties is presently limited, but new varieties are being developed.

Research done at Ridgetown College, University Of Guelph, on Fusarium head blight (FHB) management has led to a mycotoxin prediction model (DON or vomitoxin). The model was developed over many years (1996–2000) and in 399 Southern Ontario wheat fields. It continues to be modified and is quite innovative since it relates DON accumulation in the wheat grain to the environmental conditions surrounding heading and how it relates to inoculum production, wheat head infection and subsequent fungal growth within the head. Visit the *Fusarium* Web site at www.ridgetownc.on.ca/OWN/Fusarium/Fusarium_Frame.htm. to view prediction maps for Ontario.

Tan Spot

Incidence: Tan spot has been increasing in the province as a result of reduced tillage. Economic losses from tan spot have not been significant. However, the disease is often confused with Septoria leaf spot and misdiagnosis could result in unnecessary applications of foliar fungicides. Barley and oats are much more tolerant to tan spot than wheat.

Appearance: Tan spot begins on the lower leaves as small, tan-brown flecks that enlarge into oval- or lens-shaped tan lesions (5–15 mm) with a small, dark brown centre. A bright yellow zone or halo surrounds the tan lesion. The lesion is best viewed when the leaf is held to the sun.

Disease Cycle: The fungus survives on wheat residues. Disease development is favoured when prolonged, cool, cloudy, humid weather occurs early in the growing season. Spores are spread by the wind.

Management Strategies: Most wheat varieties are susceptible to tan spot. Include non-host crops such as other cereals, corn, soybeans and alfalfa in the rotation.

DISEASES

Barley Diseases

Spot Blotch, Seedling Blight, Root Rot and Head Blight

Incidence: Spot blotch (see Plate 121 on page 295), seedling blight, root rot and head blight are often serious and widespread and are caused by the same fungus. The fungus overwinters in seed, barley debris and soil. All barley seed should be treated with fungicide (refer to OMAFRA Publication 812, *Field Crop Protection Guide*). To reduce the severity of spot blotch and head blight, avoid growing barley after barley, wheat or grasses. Early planting helps avoid serious disease in July. Disease is less severe on barley grown in combination with oats.

Net Blotch and Scald

Net blotch (see Plate 122 on page 295) and scald (see Plate 123 on page 296) occur especially in cool, humid seasons. Two-rowed cultivars are usually more susceptible to net blotch and scald than are six-rowed cultivars. To help prevent the build-up of these diseases, avoid growing barley after barley, plow down stubble and straw as completely as possible, and treat seed with fungicide (refer to OMAFRA Publication 812, *Field Crop Protection Guide*).

Oat Diseases

Septoria Leaf Blotch

Septoria leaf blotch in oats can cause severe damage in all recommended varieties. The disease is recognized by the appearance of mottled, light and dark brown, elongated blotches on the leaf blade, extending to the leaf sheath and culm. Advanced stages on the culm turn black, and the weakened culm breaks over easily, resulting in damage due to lodging. Avoid planting oats after oats or mixed grains. Refer to OMAFRA Publication 812, *Field Crop Protection Guide,* for fungicide options.

Oat Leaf Rust

Oat leaf rust is often serious, especially in Central and Eastern Ontario. European buckthorn is the source of the rust fungus. For fungicide recommendations, refer to OMAFRA Publication 812, *Field Crop Protection Guide.*

Oat Cyst Nematode

Damage by the oat cyst nematode is first noticed about 2 or 3 weeks after oat plants emerge, at which time heavily infected plants appear to suddenly stop growing, leaves turn pale and begin to die back from the tips downward. These plants fail to tiller, resulting in a thin stand of stunted plants that produce little grain. Below ground, the root systems are severely stunted and usually discoloured, from a pale yellow in early growth to a yellow-brown in mature plants, as compared to the clear white in healthy plants.

To confirm suspected oat cyst nematode damage, a sample of several plants with adhering soil may be sent to the Pest Diagnostic Clinic, Laboratory Services Division, University of Guelph, 95 Stone Rd. W., Guelph, Ontario N1H 8J7. A fee is charged for this service.

If oat cyst nematodes have caused damage, do not plant spring grains the following year. Use legume or row crops in the rotation. Corn can be used if the nematode population is low but will suffer damage if the soil is heavily infested. The nematode invades corn roots but does not reproduce in them; thus consecutive cropping to corn effectively reduces the population of oat cyst nematodes.

Other Crop Problems

Winterkill

Winter cereals can be destroyed during the winter and early spring period by frost heaving, ice, low temperatures and snow mould. Varieties differ in their ability to withstand these different winter stresses. This explains the regional adaptation of some varieties that may not perform well across the province.

Growers should select varieties to address the winterkill concerns of their area. Varieties grown in the Ottawa Valley need ice tolerance; those grown in the Lake Huron snow belt need snow mould tolerance, while those grown in the heavy clays of Essex, Lambton and the Niagara peninsula need resistance to frost heaving.

Frost Heaving

The freeze/thaw cycles of early spring are one of the main reasons for winterkill in Ontario. As frost goes into the ground, it works under the crown and "lifts" the plant up (see Plate 124 on page 296). If these freeze/thaw cycles are repeated enough times, the plant is ejected or "jacked" out of the soil. Roots are broken and left exposed above the soil, causing death of the plant due to desiccation. This process is referred to as frost heaving.

Deep-seeded wheat is not more resistant to frost-heaving injury. The primary root system does not anchor the plant in the soil. The secondary root system anchors the wheat plant in the soil, protecting against frost-heaving injury. The secondary root system of the wheat plant cannot develop deeper in the soil than the depth of the seed (See Figure 6–1, *Days to Emergence at Various Seeding Depths*, on page 182). When wheat is seeded deep, the plant develops the crown and secondary root system at about 2 cm (³/₄ in.) deep, as the crown develops in response to light. Regardless of planting depth, the secondary roots will not develop below 2 cm (³/₄ in.). To maximize resistance to frost heaving, wheat plants need an extensive secondary root system developed as deep as possible.

Ice

When a rapid snow melt or winter rain is followed by below-freezing temperatures, ice can form as a thick sheet across ponded areas. Even when the water is able to drain away below the ice sheet, the ice itself will prevent oxygen from getting to the plants and the wheat will essentially suffocate and die below the ice. Surface and subsurface drainage can help reduce the ponding, which leads to this problem. Should an ice sheet form (for example, during January and February), dormant wheat will only survive for approximately 2 weeks. Break the ice surface to allow gas exchange and to keep the wheat alive.

Cold Injury

Wheat will survive extremely cold temperatures before plant death occurs. Plants that have "hardened off" (gone dormant) will survive temperatures down to –24°C (–11°F). Snow cover acts to insulate the crop from extremely cold temperatures, and even 7 ¹/₂ cm (3 in.) of snow is sufficient to protect the crop from colder temperatures. Leaf tissue on plants that have not hardened off will withstand -9°C (16°F), making late spring frosts of little consequence. There was only 1 year in the last century when cold temperatures in Ontario destroyed the wheat crop.

While the wheat crop survives cold temperatures well, cold injury can sometimes reduce vigour and final yield.

Herbicide Injury

All herbicides have the potential to cause crop injury. A significant cause of herbicide injury in cereals is from residues persisting from herbicide applications in the previous crop. For post-emergent herbicide products used in the cereal crop, most injury results at or shortly after application. Spray drift from the target crop onto neighbouring non-target crops can also cause injury when the non-target crop is susceptible to the herbicide being applied. Spray overlaps are also common places to find crop injury from herbicides.

Stage of growth, crop stress, weather conditions, variety, tank mix partners and adjuvants will all affect the amount and severity of crop injury. When the target crop is under stress, its ability to metabolize a herbicide is reduced and injury may result. The type of herbicide (mode of action) is a major factor in how herbicides affect crops; in general, while contact herbicides may look worse, systemic herbicides will have longer lasting injury, which is often more severe. Late herbicide applications occurring close to heading time can interfere with pollination and reduce yield. Fungicide or insecticide applications that have herbicide residues in the spray solution may impact the crop in this way. Always read the label for information on how to reduce herbicide injury.

Specific Types of Herbicide Injury

See the OMAFRA Factsheet, *Herbicide Mode of Action Categories*, Order No. 00-061, and OMAFRA Publication 75, *Guide to Weed Control*, for herbicide trade names.

Atrazine Herbicide Injury

Atrazine residue can accumulate on headlands as a result of application in the previous year (see Plate 125 on page 296). Symptoms include a yellowing of leaf tips and margins on the lower leaves while new leaves remain green.

Glyphosate Herbicide Injury

The symptoms of glyphosate overspray on the edge of winter wheat fields (see Plate 126 on page 296) include yellowing near the growing point and on new leaves and some reddening near leaf margins. Yellow-to-brown segments may develop in heads after exposure to very low rates.

Bromoxynil Herbicide Injury

The symptoms of bromoxynil burn on the leaf tips of barley (see Plate 127 on page 296) can include a wilting, mottling, speckling and burn on the leaves. New leaves are unaffected and leaf injury rarely affects yield.

7. Dry Edible Beans

Dry beans belong to a class of legumes that are grown almost entirely for food. There are a number of classes of dry beans, including navy (white), kidney, cranberry, large white, black, pinto, pink, small red and yellow eye. Adzuki and mung beans are only distantly related. Dry beans require special cultural management practices for optimum quality and profitability.

Ontario has been one of the main white bean producing areas in North America; however, acreage in both Ontario and Michigan has been declining over the past decade. Over 80% of Ontario's white bean production is exported.

Larger, seeded coloured beans are grown where the weather is suitable for achieving the size and quality demands of the market. Acreage of the coloured bean types in Ontario and Michigan has been increasing.

Tillage Options

Research and on-farm demonstration trials have shown that edible beans can be successfully grown under either a conventional or a no-till system. However, production concerns and buyer contracts often require conventional tillage practices.

White beans respond to some form of tillage in the seed zone at planting. This is largely due to their inherently small and poorly developed root system. In a no-till system, tillage coulters on the planting unit will provide the necessary seed zone tillage. Beans are slightly shorter when grown under no-till and thus are more suitable for narrow row production. If edible beans are to be direct harvested, packing the field following planting levels the field and presses down small stones. Packing is also essential for no-till beans planted into corn stalks. This will prevent the combine from catching corn stalks and contaminating the beans with dirt.

Land planted to edible beans is susceptible to soil erosion. The crop canopy and crop residue protect the soil for a relatively short period of time. For beans in wide rows, a crop canopy may only fully cover the soil during August. Dry edible beans are also more vulnerable to soil crusting prior to emergence than soybeans. Secondary tillage should be limited to the minimum amount required to prepare a seedbed.

Table 7–1.
Crop Rotation and White Bean Yields[1]

Rotation	Average Yield		% Yield Increase vs. Continuous Beans
	kg/ha	lb/ac	
corn-alfalfa-alfalfa-beans	1,404	1,254	126
corn-beans-corn-beans	1,254	1,120	102
wheat-beans-wheat-beans	1,196	1,068	92
beans-beans-beans-beans	622	555	–

[1] Study conducted over 9 years following 25 years of sod.

Crop Rotation Considerations

A good crop rotation is the most important factor for high edible bean yields. Results from a white bean study at the Huron Research Station, Ridgetown College, University of Guelph, revealed that a good rotation produced yields 225% higher than the worst case rotation (see Table 7–1, *Crop Rotation and White Bean Yields*, above). Yield improvements were attributed to reduced disease problems and improved soil structure compared to continuous beans. A rotation where beans are grown only once in 3 years is essential to avoiding the build-up of diseases. The most common diseases encouraged by short rotations or continuous beans are Fusarium root rot and white mould. Soybeans, canola or sunflowers are not optimal rotational crops since they are susceptible to white mould (Sclerotinia) and may increase the risk of white mould in succeeding bean crops. Highest yields are often produced when beans follow sod.

Edible beans are very sensitive to certain herbicides. To reduce carry-over injury from previous crops, select herbicides carefully the year prior to bean production. Select fields with low weed pressure, as beans are not competitive with weeds. The number of herbicides available for weed control in beans is limited. Weeds present at harvest may also create quality problems with staining of beans.

Beans are very sensitive to boron and should not be grown the year after rutabagas that received boron.

For more information on appropriate crop rotations for edible beans and precautions under different tillage systems, refer to the section *Crop Rotation*, on page 18.

Variety Selection

Select varieties based on yield, maturity, standability and disease resistance/tolerance. If white beans are grown in narrow rows, select varieties with an upright plant type, since direct harvest is the only option.

Maturity – CHUs

Choosing varieties of an appropriate maturity is of primary importance (see Figure 3-1, *Crop Heat Units Available for Corn Production*, on page 57, for the heat unit rating for your area). Selecting full-season varieties will make maximum use of the growing season and offer the opportunity for maximum yield. Select varieties that will mature within the first half of September when the weather is usually more favourable for harvest. Harvesting in dry weather will help maintain high-quality beans.

If white beans are to be grown in no-till, select an upright variety, since direct harvest is the only option. For a listing of varieties and their heat unit ratings, refer to the OMAFRA Factsheet, *Performance Trials for Dry Edible Beans*, at www.gov.on.ca/OMAFRA/english/crops and distributor information. Maturity of beans is rated for two areas: full/mid-season and short-season areas. The differences between these general areas have more influence on a variety's "days to maturity" than does the planting date.

Biotechnology

Since the current markets for dry edible beans prefer to receive only traditionally bred varieties, there are no transgenic (GMO) varieties grown in Ontario.

Planting and Crop Development

Seed Quality

Use only pedigreed seed, which is free from mechanical injury and weather damage. Common bacterial blight can be a serious seed-borne disease some years, and for this reason only certified seed from inspected fields should be used. All seed should be tested for germination ability. See Appendix H, *Ontario Seed Laboratories Accredited by the Canadian Food Inspection Agency*, on page 263. Poor-quality seed can result in uneven emergence, stunting or bald-headed plants (i.e., plants without true leaves).

Table 7-2.
Planting Date Guidelines

Geographic Area	Planting Date Guideline
Less than 2,700 CHUs	May 26 – June 6
2,700 – 2,900 CHUs	May 30 – June 10
Greater than 2,900 CHUs	June 7 – June 20

Planting Date

Table 7-2, *Planting Date Guidelines*, above, displays the guidelines for planting dates according to geographic regions.

The highest yields are obtained by planting within these planting dates. The planting date of coloured beans is dependent upon both variety and the number of crop heat units. Check with the seed distributor for planting recommendations.

The ideal soil temperature for germination is above 15.5°C (60°F). Edible beans are less vigorous than soybeans. As a result, they are more prone to emergence problems from soil crusting, deep planting and/or cool, wet soils. Planting within the appropriate planting dates will allow the crop to avoid hot, dry weather during flowering and allow for a timely harvest. Edible beans are less able to adapt to a shorter growing season from late planting than soybeans. Under late planting conditions, carefully consider when edible beans will mature before continuing to plant.

When late planting cannot be avoided, consider switching to soybeans.

Seeding Rates and Depth

Edible bean seed size varies greatly. Check to ensure that the planter is calibrated properly to plant the correct number of seeds per metre of row. Table 7-3, *Seeding Rates for White Beans According to Row Width*, on page 217, displays the seeding rates for white beans according to row width. Seeding rates should be adjusted for seed quality and germination, field conditions, and field history.

For large, seeded coloured beans, the recommended seeding rate is 11.5–16.4 seeds/m (3.5–5 seeds/ft) in 53–76 cm (21–30 in.) rows. For specifics on seeding rates, consult with the seed supplier. In conditions

Table 7-3. Seeding Rates for White Beans According to Row Width

		Row Width cm (in.)		
		36 (14.5)	53 (21)	76 (30)
		Number of Seeds/m of Row[1] (Seeds/ft)		
		10–13 (3-4)[2]	11.5–15 (3.5–4.5)[3]	15–16 (4.5–5.0)[4]
Number of Seeds/kg.	Number of Seeds/lb.	Seeding Rate (kg/ha)		
4,500–5,000	2,000–2,300	72–83	54–62	42–48
5,000–5,500	2,300–2,500	66–72	50–54	38–42
5,500–6,000	2,500–2,700	61–66	46–50	36–38
6,000–6,500	2,700–3,000	55–61	42–46	32–36

100 kg/ha = 90 lb/ac

[1] Adjust seeding rates for germination percent and expected percent emergence.

[2] Seeding rate of 369,000 viable seeds/ha (150,000 seeds/ac).

[3] Seeding rate of 272,000 viable seeds/ha (110,000 seeds/ac).

[4] Seeding rate of 222,000 viable seeds/ha (90,000 seeds/ac).

where reduced emergence is a risk, seeding rates should be increased up to 10%. High-risk conditions could include seeding into heavy soil, late or very early planting, deeper plantings or expected seedling loss from wireworm or seed corn maggot injury.

The seeding depth for dry edible beans is critical for even emergence. Frequently poor stands are the result of not seeding into moisture. Planting depth should be at least 1.2 cm (½ in.) into soil moisture. Uneven emergence results in uneven maturity. A seeding depth of 4-6 cm (1½–2½ in.) is normal, but deeper plantings of up to 9 cm (3½ in.) may be necessary to seed into moisture. Beans planted deeper are more susceptible to crusting problems. Some older drills cannot provide accurate depth control. In these situations, a planter may be a better option. Rolling or packing a field prior to planting helps to firm the seedbed and conserve moisture, and can help to control planting depth when seeding with a drill. Packing after planting helps to level out ridges, pushes down small stones and conserves moisture. However, it also makes the soil more susceptible to crusting.

Row Width

Row widths of 70–75 cm (28–30 in.) are standard for both white beans and coloured beans when the bean crop is to be pulled and windrowed. Narrow row widths of 36–56 cm (14–22 in.) are most suitable if the white bean crop is to be direct harvested. Row width trials with no-till white beans produced yields 14% higher in narrow row widths (i.e., under 56 cm or 22 in.) compared to wide rows. In narrow rows, select white bean varieties with an upright plant type and good tolerance to white mould. The percentage of emergence may be greater in wide rows seeded with a corn planter than solid-seeded with a grain drill due to:

- more uniform and accurate seed depth placement
- better seed coverage
- more seeds per linear metre (foot) of row to push up through a surface crust, i.e., 16 seeds/m (5 seeds/ft) of row in 76-cm (30-in.) rows versus 10-13 seeds/m (3-4 seeds/ft) in 36-cm (14-in.) rows
- seeds not being planted in tractor tracks

In narrow rows, emergence can be a problem for beans planted into tractor tracks. Some growers adapt equipment to harrow or cultivate between the tractor tires and the planter. When direct harvest is planned for fields with a history of white mould, a cultivar with a low white mould infection score should be chosen. Planting the crop in wider rows and reducing population may help reduce the incidence of white mould disease. The advent of rod pullers has enabled beans planted in 50-56 cm (20-22 in.) rows to be pulled and windrowed.

Inoculation

Inoculation trials with edible beans have shown no advantage to the use of inoculate.

Rotary Hoeing

Occasionally, a crust will form on the soil, which inhibits bean emergence. A rotary hoe can be used to break up a crusted soil surface to allow seedlings to emerge. Typically, the rotary hoe can reduce bean stands by 5%–10%, but the extra beans that emerge more than compensate for this reduction. Rotary hoeing during the "hook" stage of bean emergence will result in significant plant losses.

The rotary hoe can also be beneficial in weed control. See the section *Weed Control*, on page 221, for more information on mechanical weed control.

Replant Decisions

A number of factors can cause reduced bean stands. These include soil crusting, herbicide injury, frost, hail, insects and diseases. The decision to replant can be one of the most difficult decisions for a producer to make. Consideration must be given to the cause of the poor stand, the date of replanting, the remaining population of healthy plants and weed control needs.

**Table 7–4.
Phosphate and Potash Recommendations for Dry Edible Beans
Based on OMAFRA-Accredited Soil Tests**

Sodium Bicarbonate Phosphorus Soil Test (ppm)	Rating	Phosphate (P_2O_5) Required kg/ha	Ammonium Acetate Potassium Soil Test (ppm)	Rating	Potash (K_2O) Required kg/ha
0–3	LOW	80	0–15	LOW	120
4–5		60	16–30		110
6–7		50	31–45		90
8–9		40	46–60		80
10–12	MEDIUM	30	61–80	MEDIUM	60
13–15		20	81–100		40
16–25	HIGH	0	101–120		30
26–60	VERY HIGH	0	121–150	HIGH	0
61 +	EXCESSIVE[1]	0	151–250	VERY HIGH	0
			251 +	EXCESSIVE[1]	0

100 kg/ha = 90 lb/ac

[1] There is no expected agronomic response from the additional application of nutrients, and there is the potential for additional application of the nutrient (commercial fertilizer and/or manure) to reduce crop yield and/or quality. For example, additional phosphorus application to a soil testing more than 60 ppm of phosphorus could induce a zinc deficiency on soils low in zinc and may also increase the risk of nutrient movement into groundwater, while additional potash application to a field already testing more than 250 ppm of potassium could induce magnesium deficiency on soils low in magnesium.

Normal seeding rates include a margin of safety to ensure emergence of an adequate stand. Cranberry beans generally perform better than white beans or other coloured beans under late-planting scenarios.

Plant Development

Dry edible beans develop similarly to soybeans (see the section *Planting and Crop Development*, on page 100). Two basic plant types are found in edible beans, determinate (bush) or indeterminate (vining). Some early varieties are determinate in growth where the stem stops upward growth when flowering begins. Vining types continue to develop new growth even when flowering begins, which can allow these types to withstand more stress than determinate types. Edible beans are less tolerant of stress than soybeans, which underlies the importance of fast, even emergence for a healthy stand that is competitive. The optimum temperatures for dry bean development are 18°C–24°C (65°F–75°F). Beans with uneven emergence will be uneven in maturity. Beans can compensate for less than full stands, provided the remaining stand is healthy.

Fertility

Nitrogen

Nitrogen fertilizers are not usually necessary for dry edible beans. However, where phosphate fertilizers are banded, a small amount of nitrogen (10 kg N/ha) may improve the availability of the phosphate. Where field bean yields have been low due to bronzing or root rots, apply up to 100 kg/ha of nitrogen before planting. Under these conditions, nitrogen will increase yield but will not cure the bronzing or the root rot. Seed size was found to increase slightly by the application of nitrogen. Nitrogen application potentially can delay maturity, particularly following high legume sod or where manure is applied.

Phosphate and Potash

Phosphate and potash recommendations for dry edible beans are presented in Table 7–4, *Phosphate and Potash Recommendations for Dry Edible Beans Based on OMAFRA-Accredited Soil Tests*, above. For information on the use of this table or if you do not have an OMAFRA-accredited soil test, refer to the section *Fertilizer Recommendations*, on page 31.

Methods of Application

In order to avoid seed burn, do not place fertilizer in contact with the seed. The fertilizer may be broadcast and plowed down or worked in before planting, or a planter with a separate attachment for fertilizer placement may be used to place the fertilizer 5 cm to the side and 5 cm below the seed. For further information, see Table 2–30, *Maximum Safe Rates of Nutrients*, on page 47.

Table 7–5.
Interpretation of Plant Analysis for Dry Edible Beans

Nutrient	Units	Critical Concentration[1]	Maximum Normal Concentration[2]
Nitrogen (N)	%	4.00	5.5
Phosphorus (P)	%	0.15	0.5
Potassium (K)	%	1.20	2.5
Calcium (Ca)	%	–	5.0
Magnesium (Mg)	%	0.10	1.0
Boron (B)	ppm	10.0	55.0
Copper (Cu)	ppm	4.0	30.0
Manganese (Mn)	ppm	14.0	100.0
Zinc (Zn)	ppm	14.0	50.0

[1] Yield loss due to nutrient deficiency is expected with nutrient concentrations at or below the "critical" concentration.

[2] Maximum normal concentrations are more than adequate but do not necessarily cause toxicities.

Plant Analysis

For dry edible beans, sampling the top fully developed leaf (three leaflets plus stem) at first flowering is recommended. See Table 7–5, *Interpretation of Plant Analysis for Dry Edible Beans*, above. Plants suspected of nutrient deficiency should be sampled as soon as the problem appears. If sampling at other than the recommended time, samples from both healthy and injured areas should be collected so comparisons can be made correctly. A soil sample should be taken from the same area and at the same time as a plant sample. For more information, see the section *Soil Sampling*, on page 29.

Values apply to the top fully developed leaf (three leaflets plus stem) at first flowering.

Micronutrients

Manganese

Manganese deficiency has been diagnosed occasionally in beans in Ontario. This problem is more likely to occur on muck soils or on very sandy soils. Plants with manganese deficiency have pale green-to-white upper leaves. The veins of affected leaves will remain green. Correct the deficiency as soon as it is detected by spraying the foliage with 2 kg of actual manganese/ha (1.8 lb/ac) from manganese sulphate (8 kg/ha or 7.1 lb/ac of manganese sulphate) in 200 L (53 gal) of water. Use of a "spreader-sticker" is recommended.

In good growing conditions, the affected leaves should green up in 4–5 days. Chelated manganese products are equally effective if you apply the same amount of manganese, but they are about 10 times the price of manganese sulphate. Low rates of chelated manganese are not effective and may make the manganese deficiency worse.

In general, beans will give a profitable response to manganese in the parts of the field where manganese deficiency is showing. There is no benefit to applying manganese to beans without deficiency symptoms.

Zinc

Zinc deficiency rarely occurs in beans; it is most likely to occur in spots where the topsoil has been lost. Zinc deficiency can be corrected by foliar spray application of 0.5% zinc sulphate spray in 190 L/ha (76 lb/ac), plus wetting agent. One kilogram (2.21 lb) of zinc sulphate in 200 L (53 gal) of water makes a 0.5% solution. Zinc chelate is also effective as a spray. Soil application is not effective.

Boron

Beans are very sensitive to boron and should not be grown in a field where boron was applied to rutabagas the year before.

Harvest and Storage

Producing beans that are clean, bright and whole is the ultimate goal. Edible beans can be a sensitive crop to harvest. Weather conditions in the fall can cause some bean types to deteriorate in quality much quicker than others. Kidney, dutch brown and black beans tend to withstand more adverse weather at maturity than the white navy, cranberry and white kidney types. Larger, seeded coloured beans tend to absorb more moisture after a rain, requiring more time to dry down. It is therefore important to know the quality standards for the market class you are selling to.

The recommended range of moisture for harvest is 16%–20%. Harvesting outside this range will greatly reduce quality. Low moisture contents will increase the levels of split seeds and cracked seed coats. Wet or immature beans will become stained from the leaves, stems and dirt.

There are two common methods of harvesting dry edible beans" pulling followed by windrowing or direct-combining.

Pulling, Windrowing, Combining

Beans planted in wide rows are usually harvested after pulling, which cuts the plants 3–5 cm (1¼ in.) below

Table 7–6.
Average White Bean Harvest Loss in 1990 and 1991

Harvest Method[1]	Precleaning Loss: %		Cleaning Loss: %		Total Loss: %	
	Average	Range	Average	Range	Average	Range
Pull and windrow rod cutter	1.6	1.1–5.0	2.1	0.8–3.6	3.7	2.9–5.3
Pull and windrow knife cutter	2.3	1.1–10.9	2.4	1.4–5.7	4.7	2.6–12.3
Direct harvest finger/ air reel	6.9	2.9–10.4	1.2	0.6–1.9	8.1	3.5–11.4
Direct harvest finger reel	11.7	3.3–20	2.0	1.0–2.0	13.7	5.4–21.9

Source: Harvesting Michigan Navy Beans, Michigan State University.

[1] Includes only those trials where equipment was operating as intended.

the soil surface, and pulls plants from two or more rows into a single row with a windrower. Beans are pulled when 90% of pods have matured and turned buckskin brown. To prevent pod drop and shattering losses, beans should be pulled early in the morning when the plants are damp with dew and tough. Beans are harvested later the same day with an edible bean or conventional combine equipped with a windrow pick-up attachment. Since prolonged exposure of the mature crop to excessive moisture will result in lowered quality, it is important to harvest the crop as soon after pulling as possible. Larger-seeded bean types require specialized combines in order to meet quality standards set by the market. Under good conditions, seed losses of 3%–5% are normal during harvest (i.e., 1% loss pulling and windrowing, 1% at combine pick-up, and 1%–2% cleaning and threshing).

Direct Combining

Bean types most suited to direct harvest include white beans with upright plant type, adzuki beans, black beans and pinto beans. Larger-seeded bean types require specialized combines in order to meet the quality standards of the market.

Combine enhancements help to reduce harvest losses and minimize dirt, splits and damage to the beans. The cleaning and threshing characteristics of the crop will change throughout the day as moisture content changes. Combine set-up should include:

- Knives kept sharp to minimize shatter losses.
- Cylinders run only fast enough to thresh crop. Run as much material as possible through the cylinder to minimize seed damage. Cylinder speeds on many combines do not go below 250 rpm, which can be too fast for easily threshed beans. Cylinder slow-down kits, which include a smaller diameter drive pulley and a belt, are available.
- Unloading augers run slow and full to minimize seed damage. The short vertical auger on the combine (turret auger), which takes seed from the bottom of the tank to the main unloading auger is a point of high seed damage. Some bean growers have changed unloading augers to conveyer belt systems.
- Combine ground speed set at about two-thirds slower than when harvesting soybeans.
- Vine lifters raise low hanging pods before the plant is cut. This can be of the greatest benefit in harvesting varieties without a strong upright plant type.
- Flexible floating cutter bar adjusted to clip the bean plants as close to the ground as possible. This will help minimize the cutting of low-hanging pods and associated seed loss. The knife must cut cleanly and quickly to avoid shaking the plants, splitting pods and shattering beans. Most losses that occur are shatter loss. Ontario studies have shown that a flexible floating cutter bar can reduce losses by 25% compared to a conventional floating header. In addition a "quick-cut" sicklebar reduced loss by up to 40% compared to a standard sicklebar. Table 7–6, *Average White Bean Harvest Loss in 1990 and 1991*, above, displays the results from harvest loss comparisons made between four harvest methods on several farms in Michigan in 1990 and 1991.
- Use of an air reel to significantly improve intake of plants into the combine and reduce losses at the knife. The air blast keeps weeds and bean plants off the knife, offering better cutter bar visibility without shoving stones into the header. The biggest benefit of the air reel is established under difficult harvest conditions, when the crop is lodged or the volume of crop is reduced. Under good conditions, harvest losses may be as low as 3% regardless of whether or not an air reel is used. Late in the day as pods dry, header losses can reach more than 20% with a standard pick-up reel, while losses with an air reel are only 10%.
- A modified harvest pattern to improve yield and quality. Travelling against the direction of lodging allows the harvest of leaning branches and low-hanging pods and can reduce stubble losses by up

to 300%. In an uneven maturing or weedy crop, delay harvest in the affected areas until they are mature or they can be treated with a desiccant.

Quality Preservation at Harvest

Occasionally, the crop may be ready to harvest but the field or part of the field may still be green or weedy. Harvesting when green stems or green weeds are present may result in stained beans. Products are available for harvest aid to burn down weeds and desiccate the crop. Refer to OMAFRA Publication 75, *Guide to Weed Control*, for more information. Similarly, weeds such as Eastern black nightshade and American pokeweed can cause severe staining. Where direct harvest is intended, a desiccant should be applied to dry the remaining green tissue.

Secondary growth can occur as plants begin to mature, particularly when rainfall follows an extended dry period. White beans are more susceptible to secondary growth than coloured beans.

Special effort should be taken to maintain seed quality. Before harvesting, the combine should be cleaned of any residual seed of previously harvested crops. If on-farm storage is necessary, store individual varieties of beans in separate bins that are free from other grains and oilseeds. Harvested beans should be kept free of stones, glass and other seed-size contaminants. Failure to maintain the purity of the crop can result in lost value.

Weed Control

The critical period to control weeds in white beans is from the second trifoliate leaf stage to the first flower stage.

Critical Period for Weed Control

Season-long weed control is not necessary to protect yield. Research has shown that maintaining good weed control throughout the critical period will result in less than 5% yield loss. Later-germinating weeds have minimal impact on yields and have relatively low production of weed seeds.

The product label for postemergent herbicides indicates the growth stage of the weeds when optimum control can be obtained. The timing of weed control should optimize the critical period for the crop and the optimum growth stage of the weed.

Crop Losses Due to Weeds

Research in other crops has found that some weeds are more competitive than others. While the loss levels due to specific weeds have been well documented for corn and soybeans, crop loss data for edible beans have not yet been determined. Crop scouting is essential to determine the species present in the field and the weed populations. Consider the effect of weeds on crop quality and harvestability when making decisions on the level of weed control needed.

Mechanical Weed Control

Consider cultivation, rotation and other effective cultural practices for weed control along with herbicide treatments when developing a weed control program. Any single method of weed control or the continuous use of the same chemical can lead to the build-up of weeds resistant or tolerance to that control method. Rotation to other crops and/or other control methods will reduce the chance of developing new or unique weed infestations.

High-speed (10–20 km/h or 6–2 mph), shallow (2.5– 3 cm or 1–1¼ in.) cultivation with a rotary hoe when the beans are in the one- to two-leaf stage will help control small weed seedlings. Under dry soil conditions, rotary hoeing 7–10 days following planting will help control emerging weeds. It can also help activate soil-applied herbicides by mixing the chemical with moist soil. Rotary hoeing during mid-day when bean plants are more flaccid will reduce stand loss. Rotary hoeing is unlikely to remove many weeds that are past the two-true-leaf stage.

Inter-row cultivation may be required when weeds escape herbicide treatment; weeds should be considered as escapes when they are 5–7 cm (2–2¾ in.) high. Cultivation should be shallow to prevent exposure of untreated soil and germination of new weed seeds.

Band treatment of chemicals over the row will reduce costs by one-half to two-thirds, depending on the row spacing and width of band. Shallow inter-row cultivation will be required to control weeds between the bands.

Integrated Weed Management

Weed control in the bean crop is influenced by:

- crop rotation
- row width
- variety characteristics
- tillage practices

In general, the agronomic practices that produce a healthy, fast-growing crop will allow it to compete best with weeds.

Crop rotations can be effective in reducing certain perennial weeds that grow best in a particular crop.

WEED CONTROL

Narrow rows and higher populations tend to increase the crop canopy and reduce the growth of weeds, but care should be taken to balance the benefits of weed control with other requirements of the crop.

Equipment can carry weed seeds from field to field. Combines, tillage equipment and soil erosion also transport weeds. Weeds can also infest a field from manure application or other soil amendments. Proper sanitation and cleaning of equipment along with maintenance of field border areas all affect the long-term weed management in the field.

Refer to OMAFRA Publication 75, *Guide to Weed Control*, for more information including herbicide products and rates.

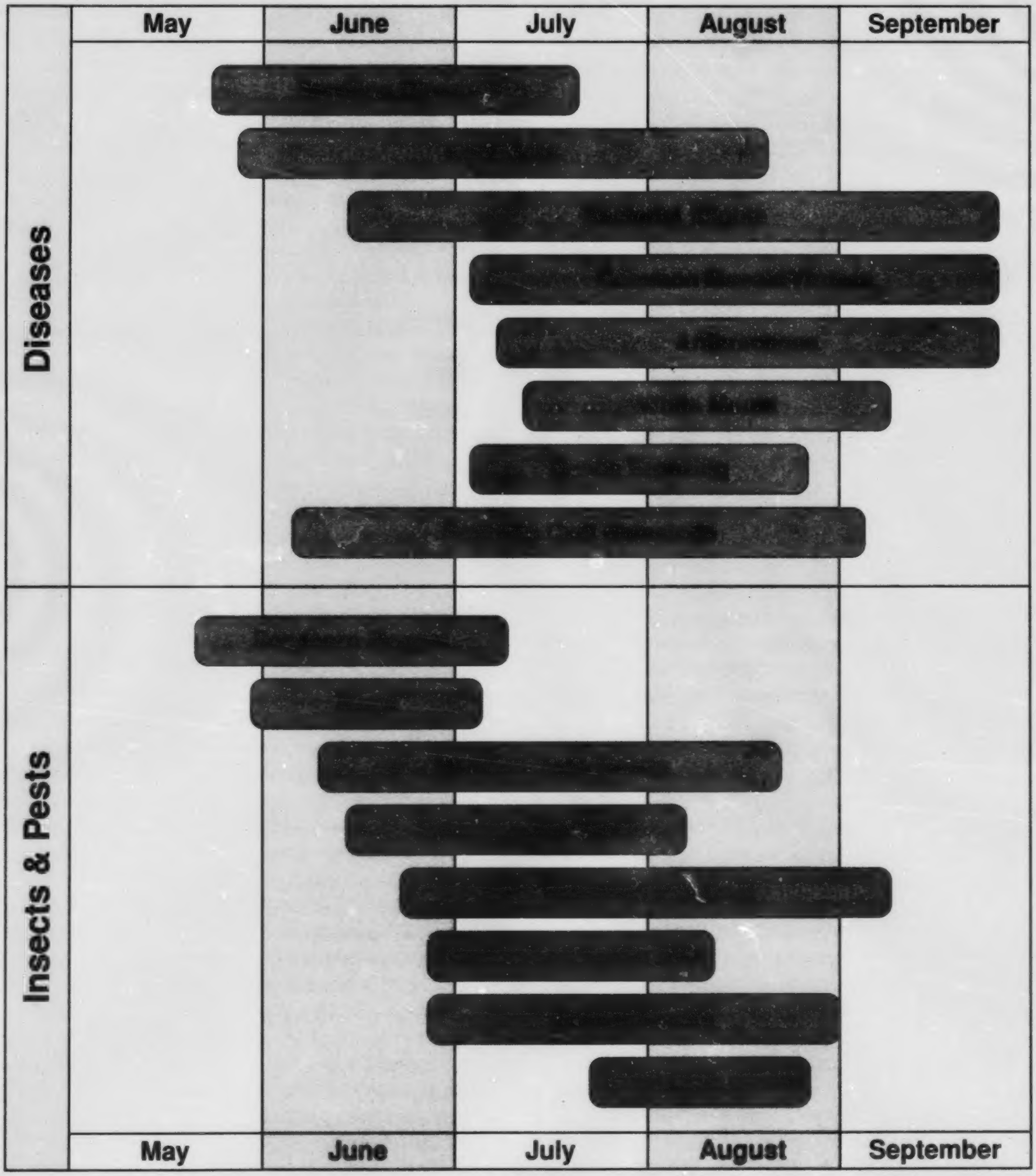

FIGURE 7–1.
Edible Bean Scouting Calendar

Insects

Table 7-7, *Symptoms in the Field*, below, shows insects and pests that could be causing the symptoms in the field.

Individual descriptions of insects and pests found in dry edible beans and recommendations for their control follow.

Table 7-7.
Symptoms in the Field

Symptom	Possible Insects or Pests							
	Grasshoppers	Green cloverworm	Mexican bean beetle	Potato leafhopper	Seedcorn maggot	Slugs	Tarnished plant bug	Wireworms
Gaps in the stand: Tunneling into cotyledon, embryo or hypocotyl					x	x[1]		x
Holes in leaves								
Ragged holes in leaf (looks like hail damage)						x		
Round holes in leaf	x	x	x					
Leaves distorted or discoloured								
Margin of leaves yellow or appear scorched. Leaves puckered				x				
Flower blasting or young pod drop							x	
Pod/Seed – feeding insects								
Hard dark spots on pods and seed							x	

[1] Slime trail noticeable.

Seedcorn Maggot

Description: The seedcorn maggot is a small, yellowish-white, headless, legless larva (see Plate 53 on page 283). The body tapers to the front with two small mouth hooks protracting. The maggots burrow into germinating seeds and the below-ground parts of emerging seedlings, producing weak seedlings.

Life History: Seedcorn maggot adults (flies) will mate, and the female will search for an egg-laying site from April until the middle of June. The females are attracted to moist soils that give off an odour of decaying organic matter such as crop residues, areas where manure has been applied or freshly tilled soil. Weeds are also attractive to females. The adults lay their eggs in the soil. The larvae then develop in the soil and organic residue, feeding on germinating seeds.

Damage: The maggots feed on the swollen, ungerminated seed. They can be found in the cotyledon, embryo and hypocotyl. Slow emergence and/or reduced stand establishment can occur. Seedlings that escape and germinate often die or lag behind.

Scouting Technique: Unlike wireworm, seedcorn maggot damage is usually found over a generalized large portion of the field. Nothing can be done to rescue a damaged field except replanting if necessary. High risk factors include freshly tilled soil with heavy crop residue, recently applied manure, recently tilled green manure, deep planting, along with cool, backwards emergence conditions in the forecast.

Action Threshold: Not available.

Management Strategy: Consider insecticide seed treatments in early-planted fields where large amounts of manure or residue have been recently incorporated or primary tillage has recently occurred. Use good-quality seed that will emerge quickly. See OMAFRA Publication 812, *Field Crop Protection Guide*, for recommended registered products. There are no rescue treatments available.

Potato Leafhopper

Description: Potato leafhopper (PLH) adults are pale-green, wedge-shaped, winged insects about 3 mm long with piercing and sucking mouthparts (see Plate 56 on page 283). Adults are broadest towards the head, with the body tapering evenly to the wing tips. There is a row of six rounded white spots behind the head. The wingless nymphs are smaller than adults.

Life History: PLH does not overwinter in Ontario. Leafhoppers generally migrate north every spring, carried along by southerly, weather fronts that start in the Gulf of Mexico. Adults generally arrive by late spring, feeding first on alfalfa and other perennial legumes. PLH generally does not appear on beans until late June after alfalfa has been cut. Occasionally, huge numbers of leafhoppers may arrive "overnight" from the south resulting in a damaging population on seedling beans. Females lay their eggs in the main veins and petioles of the leaves. Development from egg to adult takes approximately 2–3 weeks.

Damage: PLH feed by piercing plant tissue and sucking plant sap. While doing this they damage the vascular cells, which block the veins causing plant nutrients and products to accumulate in the leaf. This causes the leaves to curl and pucker, and eventually the leaf edges begin to scorch. These symptoms are called hopperburn. Border rows are affected first. Because yield is lost before hopperburn is seen, do not use the presence of hopperburn as a management guide. Leafhoppers tend to come into soybean and edible bean fields after neighbouring alfalfa fields are cut. The symptoms of potato leafhopper are commonly confused with herbicide injury problems, nutrient deficiency and drought stress. High risk factors include hot, drier-than-normal seasons.

Scouting Techniques: Walk in an "X" pattern. In 10 areas of the field, pick 10 trifoliate leaves that are newly and fully expanded from the centre of the plant canopy.

Action Thresholds:

Bean Growth Stage	PLH Threshold per Trifoliate (adults and nymphs)
Unifoliate	0.25
Second trifoliate	0.5
Fourth trifoliate	1.0
First bloom	2.0

Management Strategies: Use of systemic insecticides at planting may help to control the pest. Refer to OMAFRA Publication 812, *Field Crop Protection Guide,* for recommended insecticides. A naturally occurring fungal pathogen helps reduce the populations of the PLH under cool, moist conditions. Predators and parasites appear to play a minor role in controlling the pest.

Defoliating Insects

Research conducted at Ridgetown College/University of Guelph (see Figure 7-2, *Yield Loss Versus Defoliation of Navy Beans,* right) indicates that prior to flowering, beans are able to tolerate up to 50% leaf loss with minimal loss in final yield. Complete defoliation prior to flowering delayed maturity by 30 days. Lower levels of defoliation did not delay maturity. At later stages, the impact of defoliation is greater. Total losses will be determined by the growing conditions and the ability of the plant to recover. Losing more than one-third of the leaves during flowering or pod fill can greatly reduce yield.

As a general guideline, use Table 4-20, *Standard Damage Thresholds for Soybean Insect Defoliation,* on page 120, as a threshold for management decisions.

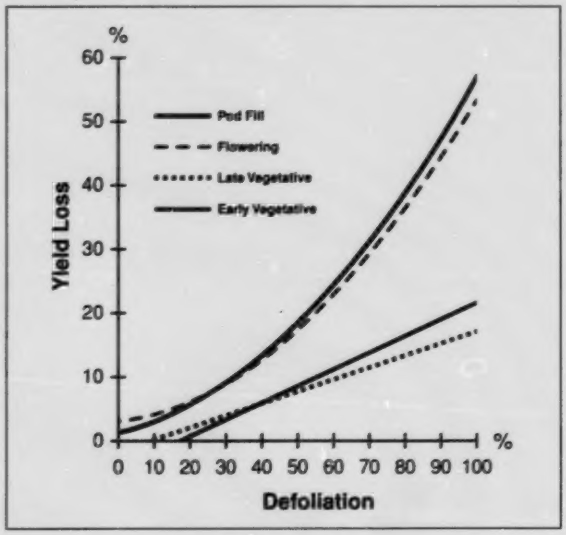

Figure 7-2.
Yield Loss Versus Defoliation of Navy Beans
Source: Schaafsma and Ablett, 1994.

Green Cloverworm

Description: The adults are dark brown or black moths with spotted wings. Their wingspan is approximately 2.5 cm (1 in.) The larvae are pale green, approximately 2.5 cm (1 in.) in length and have two white longitudinal stripes running along the length of the back (see Plate 128 on page 296). The larvae will pulsate when disturbed. Green cloverworm attack alfalfa, bean, clover, cowpea, soybean, strawberry, vetch, many common weeds and other legumes.

Life History: Green cloverworm overwinter as pupa in leaf litter and crop debris. Once spring temperatures rise, adults become active and lay eggs on the underside of leaves. Eggs hatch, and the larvae feed on the foliage for approximately 1 month before burrowing into the soil or crop debris to pupate. There are two generations per year.

Damage: Larvae feed on bean foliage and pods, causing holes and reducing yield if in high numbers.

Scouting Technique: Scout 10 plants in five locations across the field. Shake plants over a piece of paper and count the number of larvae found per 30 cm (12 in.) of row.

Action Threshold: More than five larvae per 30 cm (12 in.) of row warrant control.

Management Strategies: Several natural enemies help to keep populations below economic thresholds. Insecticides are only recommended if populations are extremely high, as they will also kill the natural enemy population. For more information on insecticide recommendations, refer to OMAFRA Publication 812, *Field Crop Protection Guide.*

Mexican Bean Beetle

Description: This is the only member of the lady beetle family in Ontario that eats plants. All the other lady beetles are beneficial predacious insects. The adult beetles are oval in shape, approximately 6 mm (¼ in.) in length with 16 small black spots on their coppery-red backs, resembling a lady beetle (see Plate 129 on page 297). The heads of the Mexican bean beetle, however, are the same coppery-red colour as their backs, whereas lady beetles' heads are typically black and white. Adults will darken with age to an orange-brown colour. The larvae are yellow and have six rows of long, branching, black-tipped spines along their backs.

Life History: This pest overwinters as adults in grassy fencerows and wooded areas. The adults emerge in May and begin feeding on young bean plants. Eggs are laid on the underside of the bean foliage. Larvae hatch, and young larvae feed in clusters. As they mature, larvae will scatter more. Feeding continues for approximately 1 month before larvae attach themselves to the plant and pupate. Adults emerge approximately 2 weeks later. There are one to two generations per year.

Damage: Both the adult and larvae feed on the leaves, flowers and pods, but most injury is concentrated on the leaves. First symptoms are large holes, but as feeding continues, the entire leaf is consumed except for the leaf veins. Damage is usually localized.

Scouting Technique: Examine 10 plants at five locations across the field. Monitor border rows.

Action Threshold: Substantial yield loss does not occur until up to 35% defoliation occurs before bloom and 15% after bloom. If border plants show evidence of Mexican bean beetle, a border spray may be necessary.

Management Strategies: Insecticide is only recommended if pest populations and damage are extremely high, as insecticide will kill the natural enemies as well. Refer to OMAFRA Publication 812, *Field Crop Protection Guide,* for insecticide recommendations.

Control weeds along borders and fencerows to expose adults in their overwintering sites. Several natural enemies keep this pest under action thresholds.

Grasshoppers

Damage: Both adults and nymphs feed on the leaves and pods, including the seeds. High infestations can defoliate fields and cause yield loss. Feeding damage usually begins around the borders of fields, adjacent to grassy fencerows and pasture. Risk factors include neighbouring grassy fields and drought conditions.

Life History: Grasshoppers overwinter as eggs in the soil, usually in uncultivated fields and pastures.

Nymphs hatch from the eggs in early June and begin feeding on emerging plants. Nymphal stages last for approximately 2 months with adults appearing later in the season to feed, mate and oviposit their eggs in the soil for next year's population. Grasshoppers prefer to lay eggs in sandy soils with grassy, undisturbed areas. Drought conditions for 1–2 years favour egg and nymph survival.

Scouting Technique: Begin scouting in late June when grasshoppers are still young. Scout adjacent fencerows and grassy borders.

Action Threshold: Substantial yield loss does not occur until up to 35% defoliation occurs before bloom and 15% after bloom. If border plants show evidence of grasshoppers, a border spray may be necessary.

Management Strategies: Early-season control should be concentrated on the boundaries of the field in those areas with high nymphal populations. Refer to OMAFRA Publication 812, *Field Crop Protection Guide,* for insecticide recommendations. Several natural enemies, including ground beetles and crickets, feed on the egg stage, while birds and spiders feed on the nymph and adult stage, helping to reduce the populations. The fungus *Entomophthora grylli* can reduce the populations when weather conditions are warm and humid. Removal of grassy weeds in fields and borders by tillage helps reduce nymphal numbers that require these plants to survive. Tillage buries eggs deeper in the soil, hindering nymphal emergence. Chemical control is more effective on nymphal stages than adults.

Diseases

General Preventive Measures

1. All equipment used for cleaning, conveying or planting seed should be thoroughly washed with detergent to remove all soil. The equipment should then be disinfected with a quaternary ammonium compound (for example, Niagara HY-X) or sodium hypochlorite (for example, 10% Javex). Rinse off the disinfectant with clean water to limit rusting of treated surfaces.
2. Use a 3–4-year rotation with non-related crops.
3. Do not apply manure containing bean refuse to land intended for beans.
4. Stay out of bean fields when the foliage is wet to avoid spreading diseases.

Bacterial Blights

Incidence: There are several different bacteria that cause significant damage in edible beans. In Ontario, common blight and halo blight are the primary bacterial diseases of this crop. Most bean varieties are susceptible to common bacterial blight, but most are resistant to halo blight.

Appearance: These diseases are difficult to distinguish between. Both begin as small, water-soaked spots on the leaflets. In the case of common bacterial blight, these water-soaked lesions are dark and first appear on the underside of the leaflets. These spots enlarge and will join together to form large, brown, dry areas between the veins. Both of these diseases cause a thin, bright yellow border surrounding the infected areas, however, for halo blight, this border is broader and more noticeable (see Plate 130 on page 297). Under hot conditions, these borders may not form.

As these blights develop, the infected leaves become brittle and will drop prematurely. Infected plants may lose their leaves a week or two earlier than healthy plants. In severe cases, the small veins and midrib will turn a reddish colour. Leaves infected with halo blight will curl and the younger leaves become yellow, having no noticeable halos or dead spots.

Symptoms on the pods also begin as round, water-soaked lesions with a yellow or cream-coloured mass of bacteria in the centre of these spots. Over time, these pod lesions become sunken and dry with a reddish-brown border surrounding the yellow centre. The earlier the infection occurs on the pods, the greater the impact on seed quality. Seed is often shrivelled and, in the case of common bacterial blight, it may yellow. Planting infected seed produces plants that have a stem girdling or joint rot above the cotyledonary node. The plant is weakened and may fall over.

Disease Cycle: These bacteria do not normally overwinter in Ontario and therefore survive from one year to the next in infected seed. Once the plants are infected, the disease may be spread from infected to healthy plants by storms, people and equipment moving from field to field when the plants are wet.

Rain and hail can also spread the bacteria through the field.

Management Strategies: The bacteria usually do not overwinter in the field but, to be safe, allow 1 year between susceptible crops. Do not plant seed that has been harvested from infected fields. Also, do not plant this year's crop next to a field that had significant blight in the previous year. Incorporate infected bean debris into the soil after harvest. Bacterial blights spread easily when plants are wet from rain or dew. Stay out of wet fields with equipment and workers. Clean cultivators when moving from field to field. Recently, varieties have been developed that have genetic resistance to bacterial blight. These bacterial blight-resistant white bean varieties are becoming available to Ontario growers.

Anthracnose

Incidence: Anthracnose was once the most economically important edible bean disease in Ontario but recently has been well managed with resistant varieties and seed treatments. In fields where the disease does develop as a result of the delta strain infection of the fungus, significant damage can result.

Appearance: Plant symptoms include round, angular or oval lesions on the leaves, stems and pods (see Plate 131 on page 297). The lesions are sunken or "crater-like," with a distinct black ring along the edge of the lesion. Often, the centre of the lesion is covered with numerous small, black spore masses. The veins on the lower leaf surface are often red-brown or purple-red. Yield loss is due to early leaf senescence and plant death, shrunken seed and an increase in "pick" (seed that has disease lesions on the seed coat).

Disease Cycle: The fungus survives from year to year primarily as spores or lesions on the seed. Planting clean seed is critical to controlling the disease. Once initial infection occurs in a field, the disease can be spread by the movement of farm machinery, animals and humans, both within the field and between an infected field and a non-infected field. Rainy weather favours this disease, as spores are splashed from diseased areas and carried in wind-borne water droplets or by surface water throughout the field. Wet conditions over a prolonged period of time can result in epidemics.

There are several races (or strains) of anthracnose. All races of the disease cause the same plant symptoms. All of the currently recommended varieties of white bean are resistant to beta and gamma races of anthracnose. Consult the OMAFRA Factsheet, *Performance Trials for Dry Edible Beans,* or visit the Web site at www.gov.on.ca/OMAFRA.english/crops each year, for varieties resistant to the alpha and delta races.

Management Strategies: To avoid anthracnose, plant disease-free seed and use a fungicide seed treatment. Incorporate infected bean debris into the soil after harvest and rotate beans with other non-host crops for at least 2 years. Stay out of bean fields when the plants are wet.

To have a seed lot tested for anthracnose, contact:

Laboratory Services Division
Food Production and Inspection Branch
Agriculture and Agri-Food Canada
Laboratory Services Building
#22 Carling Ave.
Ottawa, Ontario
K1A 0C6
Telephone: (613) 759-1224
Contact: Dr. Jim Sheppard

Bean Common Mosaic Virus

Incidence: Bean common mosaic virus has been found wherever edible beans are grown in the province. In some years, the disease can be severe in individual fields.

Appearance: Infection of edible beans with the virus can cause various symptoms. Leaves of infected plants have a mosaic of light yellow-green and dark green patches that are puckered. The leaves curl downward along the margin. Plants are stunted and if infection occurs early, they may flower but not produce seed. Another symptom referred to as "black root reaction" is displayed in varieties containing a specific gene (dominant resistant gene I). These varieties are resistant to all strains of bean common mosaic virus except when plants that are growing at high temperatures react to the virus (hypersensitive response), causing the "black root reaction." The result is a browning or blackening of the vascular tissue inside the stem, wilting and plant death. The obvious symptom of "black root reaction" is the discolouration or streaking of the outer stem (water-conducting tissue), which produces a black or brown outer streaking of the stem from the soil line up. This blackening may only be visible on one side of the stem.

Disease Cycle: The virus is primarily spread from field to field through infected seed. Aphids can then spread the virus within the field. Severe losses occur when susceptible varieties are infected early either through infected seed or from being close to other infected plants or fields that have high aphid populations. There are several strains of the virus, but the predominant one in Ontario is strain 1.

Management Strategies: Do not plant seeds harvested from diseased plants. For a list of disease-resistant varieties, consult the OMAFRA Factsheet, *Performance Trials for Dry Edible Beans,* or visit the Web site at www.gov.on.ca/OMAFRA/english/crops each year. Avoid damaging the plants during cultivation.

Root Rot Complex

Incidence: There are many organisms that cause root rot symptoms on edible beans. In Ontario, the four main fungal pathogens are *Fusarium, Pythium, Rhizoctonia* and *Chalara* (formerly *Thielaviopsis*). These organisms can occur individually or in combination, as is often the case. This is referred to as "root rot complex." The amount of damage is related to the general health of the crop, past history, cultivar susceptibility and environmental conditions.

Appearance: Symptoms can appear on plants at any stage of development. Early-season infection results in typical preemergence (seed decay) and postemergent (seedling death) "damping-off" symptoms, thereby reducing plant stands, referred to as poor emergence (see Plate 132 on page 297). Plants that survive early infection ("damping-off") or become infected later display characteristic "root rot" symptoms such as discoloured roots, stunting, wilting, etc.

Fusarium root rot begins as small, reddish-brown lesions (in the first few weeks) that, as the plant ages, join to form larger lesions or streaks on the taproot surface. A reddish-brown internal discolouration of the water-conducting tissue can be seen by splitting the taproot, crown and lower stem. Adventitious roots may develop on plants that have a damaged taproot. These adventitious roots are formed above the damaged area. Late infection seldom results in dead plants but rather in stunted, weak-looking ones.

Pythium root rot has a characteristic brown, water-soaked (wet) lesion that starts at the base of the taproot. This lesion advances up the root and stem, eventually stopping 2 or 3 cm above the soil line. Seedlings are often killed, resulting in stand establishment problems. Although older seedlings and mature plants may not die from *Pythium* infection, their roots are often pruned, resulting in a stunted, poorly anchored, wilted and unhealthy looking plant.

Rhizoctonia root rot forms reddish-brown, sunken lesions on the stem and taproot, most frequently near the soil line. The lesion can girdle the entire stem, causing stunting or death of the plant. This lesion is distinctively "brick-red" in colour, noticeable immediately after removing the plant from the soil. This is one method of distinguishing Rhizoctonia root rot from Fusarium root rot. The intensity of the "brick-red" colour will fade rapidly with exposure to the air.

Charla or "black root rot" results in brown-to-black lesions being formed on the taproot and lateral roots. Under severe conditions, the entire taproot may be black.

Disease Cycle: These fungi survive in the soil in plant debris or as mycelium. They are attracted to the sugars and exudates released by the developing roots. They are most problematic when environmental conditions are cool, wet during planting or when these conditions result in a delay in seedling emergence or development. Mid- to late-season moisture stress (dry conditions) will increase the amount of Fusarium and Rhizoctonia root rots.

Management Strategies: Eliminating these diseases is impossible, but yield losses from these diseases can be reduced by following good soil management practices:

- Select culitvars that have good general tolerance to root rots.
- Promote root growth through good fertility programs. Keep organic matter content as high as possible.
- Maintain or build up good soil tilth by following a good crop rotation (3 years between bean crops of any kind), not overworking the soil and avoiding working it when it is too wet.
- Remove excessive water through increased tile drainage and minimized compaction.
- Apply seed treatments that will help protect the plant from root rots during germination and early growth. Refer to OMAFRA Publication 812, *Field Crop Protection Guide,* for seed treatment recommendations.

White Mould (Sclerotinia)

Incidence: White mould is a difficult disease to predict, although the appearance of the disease is often higher in edible beans than in soybeans in most years. The disease is most damaging when cool (moderate), wet conditions occur during flowering or near harvest.

Appearance: Initial infection takes place on plant tissue such as older flowers or possibly lower leaves that have died from other causes. Infection of healthy pods, stems and leaves results from infected plant parts coming in contact with healthy plant tissue. Infected areas are bleached, and white tufts of mould (mycelium) are usually present on the plant surface (see Plate 133 on page 297). Hard, black sclerotia are produced on the stem surface or within the stem (see Plate 134 on page 297).

Management Strategies: The following practices will help minimize losses to white mould.

- Use less-susceptible varieties or varieties with an upright plant stance.
- Other field crops, such as soybeans, sugarbeets, canola, sunflowers and hemp, are all susceptible to white mould. In fields with a history of white mould, edible beans should not follow these crops. If this is not possible, rotate 3 or more years between susceptible crops.
- Increase air movement by planting at recommended rates and proper row widths; this will reduce humidity and make the environment less favourable to white mould development. Avoid excessive use of fertilizers, which results in rapid canopy closure, making the environment favourable to infection by increasing humidity.
- Foliar fungicides have provided some control. For effective control, foliar sprays must be applied at first bloom, prior to the appearance of disease. See OMAFRA Publication 812, *Field Crop Protection Guide,* for recommended fungicides. Sprays applied after the disease first appears do not control white mould effectively.

Soybean Cyst Nematode

Although soybeans are the major host, soybean cyst nematode (SCN) has a wide host range that includes dry edible beans. Soybean cyst nematode has been increasing in edible bean-producing areas of the province. Planting edible beans into SCN-infested fields can result in an increase in "root rot complex" infection since the nematode damages the roots, allowing for easier access by these organisms. For more information on SCN, see the section *Soybean Cyst Nematode,* on page 126.

Other Crop Problems

Frost and Hail Damage

Both frost and hail can be devastating to a bean crop. The extent of early-season frost damage will depend upon where the plants were damaged. If the plant is damaged below the cotyledons, it will not recover. If the growing point is damaged, but the lower stem remains intact, the plant will send out new shoots from the base of the leaves or cotyledons. Wait a few days before replanting to see if these shoots appear.

When evaluating hail damage, check for bruising on the plant stem. Damage to the stem will make it more difficult for the plant to recover. It can also lead to increased stem disease. When the pods are damaged by hail, the seeds or entire pods will often rot.

If frost occurs close to maturity, pods that are yellow-to-brown are often sufficiently mature to escape damage. Green beans will shrivel, retain their off-green colour and increase pick. Delaying harvest until the beans dry down sufficiently will help prevent staining and will improve separation.

Bronzing

Bronzing is not caused by a living organism or pathogen but instead is the result of ozone damage to the leaf surface. A reddish-brown flecking or "bronzing" occurs on the upper leaf surface (see Plate 135 on page 298). Affected leaves are often the highest leaves on the plant; bronzing often occurs shortly following an ozone event. The number of leaves affected varies depending on exposure duration. Symptoms may be more severe on plants under moist conditions. Under dry conditions, plants are more tolerant to ozone. The amount of damage found on the plant or in an area often corresponds to air pollution alerts or heavy thunderstorms. These conditions can result in atmospheric ozone being forced down onto the crop. Ozone is also produced when lightning strikes. The higher the concentration of ozone and the longer the duration, the greater the impact on the crop. Use tolerant varieties in areas that have a history of ozone events.

Seed Quality Problems

Poor seed quality reduces germination and vigour of seedlings. Mechanically damaged seed may cause bald-headed beans (beans that emerge, but have no growing point). This injury should not be confused with symptoms of seed corn maggots, which will leave the seedlings ragged in appearance. Poor-quality seed can also cause seedlings to have broken or cracked cotyledons, or hypocotyl. Damaged seedling is more prone to diseases and insect damage. Plant only high-quality certified seed. Treat seed with a fungicide at planting to protect against seedlings. Handle seed gently to minimize mechanical damage.

Herbicide Injury

Edible beans are very sensitive to certain herbicides. To reduce carry-over injury, select herbicide for fields where beans will be rotated into the following year carefully. Consult herbicide labels for crop sensitivity and rotation information.

Specific Types of Herbicide Injury

For herbicide trade names, refer to the OMAFRA Factsheet *Herbicide Mode of Action Categories,* Order No. 00-061, or OMAFRA Publication 75, *Guide to Weed Control.*

Quizalofop-p-ethyl Herbicide Injury

Plate 136 on page 298 shows the injury due to quizalofop-p-ethyl. Symptoms appear as white-to-yellowish flecking of leaves.

Acetolactose Synthase (ALS) Herbicide Injury (e.g., imazethapyr)

Plate 137 on page 298 illustrates ALS injury on white beans. Symptoms appear as leaf yellowing in upper or lower portions of plant. Plants may also become stunted.

8. Spring and Winter Canola

Spring canola is an oilseed crop well suited to cool temperate areas of Ontario. While it is not a large acreage crop, it can be the most profitable crop grown in adapted areas. Seeding and management of winter canola is generally similar to spring canola. The differences in required management are outlined below.

Tillage Options

Conventional Tillage

Most canola is grown under conventional tillage. Because lumpy seedbeds interfere with seed-to-soil contact, fall primary tillage is preferred on clay or clay loam soils. Spring secondary tillage should be kept to a minimum to preserve as much soil moisture as possible.

The amount of tillage required will depend on soil type and spring weather conditions. Efficient tillage of stubble and control of volunteer canola and cruciferous weeds, such as wild mustard, will help reduce disease levels. This is particularly important on headlands.

Mulch Tillage

Canola performs very well with reduced tillage systems provided seeding equipment can place the seed below the residue and in firm contact with the soil. Slugs can severely reduce a stand under heavy residue cover and moist conditions.

No-Till

No-till canola has proven to be a workable system where residue distribution, weed control and fertilizer placement are optimized. The soil moisture conserved with no-till systems can be beneficial during a dry growing season. Canola is less tolerant to dry conditions than cereals. Slugs can be a problem with heavy surface residues, particularly cereal residue.

Soil Compaction

Compacted soils inhibit root growth, which in turn can result in nutrient deficiencies and drought stress in the crop. Compacted soils may remain wetter in the spring, delaying planting and increasing the potential for root rots. Soil compaction can be avoided by minimizing the number of passes across the field with heavy equipment before and after planting. Fields should not be tilled under wet conditions (refer to the section *Soil Compaction*, on page 25).

Field Variability

Canola responds to well-drained fields with a minimum pH of 5.5. Fields with variable drainage and pH will have variable stands and yield.

Variety Selection

Maturity — CHUs

Spring Canola

Spring canola is a cool-season crop that matures in approximately 100 days (90 days in Southwestern Ontario, and 125 days at New Liskeard). Cooler temperatures are required at pod set, as high temperatures cause pods to abort. Spring cereals are more resilient to dry growing conditions than spring canola. There are two predominant types of spring canola, Polish (*Brassica rapa*) and Argentine (*Brassica napus*). All current varieties in Ontario are of the Argentine type. Varieties may also be open pollinated or hybrid.

Winter Canola

Winter canola has greater yield potential than spring canola, although the gap is narrowing. Winter canola is less winter-hardy than winter wheat. Winter canola is best suited to areas with good winter snow cover, low risk of ice accumulation and moderate climate. In Ontario, the areas receiving cool winds off Lake Huron are well suited to winter canola, since the lake moderates nearby land temperatures year-round. Avoid planting winter canola in poorly drained soils and heavy clay soils, since root heaving may occur. Ice layer formation is a major cause of winterkill. Soil management practices that improve surface drainage will minimize ice formation. Winter canola is best adapted to loam soils.

Promising new varieties with improved winter hardiness and resistance to blackleg disease could soon be available, allowing winter canola production in more areas of Ontario. It is important to note that some growers in the area along Lake Huron have experienced problems with the roots of winter canola entering tile drain lines. This is evident in the year following winter canola when the roots are flushed down the tile, sometimes resulting in plugged tiles. Avoid planting winter canola in recently tiled fields and fields where standing water may remain in tiles.

Choosing Superior Varieties

Both hybrid and open-pollinated varieties are available. Yield and variety traits for the cultivars tested by the Ontario Oil and Protein Seed Committee are presented in the OMAFRA Factsheet, *Variety Recommendations for Spring and Winter Canola,* available on the OMAFRA Web site at www.gov.on.ca/OMAFRA/english/crops.

When selecting a variety, consider traits other than yield, such as lodging resistance, percentage of brown and green seeds, and free fatty acids. Variety differences exist in ease of pod shatter at maturity. This is particularly important when canola is to be direct combined.

Lodging

Lodging is scored on a scale of 1 (erect) to 5 (flat). A low lodging score is desirable for ease of harvesting and minimizing pre-harvest losses.

Brown Seeds

Seed quality is an important consideration in maintaining a market for canola varieties in Ontario. Brown seeds (prematurely aborted) are produced under stress (heat and drought) and are closely linked to high free fatty acid production.

Free Fatty Acids

Free fatty acids (FFAs) are a component that makes oils go rancid quickly. This downgrades the oil, possibly making it unsaleable, and can be a problem some years. High FFAs occur when the oil in the seed breaks down. A visual difference in brown seeds is usually linked to varietal differences. Brown seeds are brown (dead) cotyledons, rather than viable yellow ones, when the mature seed is crushed for inspection. Registration of a new variety requires the FFA levels to be lower than the current check variety.

Green Seeds

Green (immature) seeds are distinctly green when crushed. Based on crushed seed examination, No. 1 and No. 2 Canada canola grades may contain a maximum of 2.0% and 6.0% distinctly green seeds, respectively. Green seed is a problem when fields are harvested before the seeds have turned colour, or when it suffers from heat and drought stress near maturity.

Oil and protein contents, and agronomic traits such as plant height, days to flowering and days to maturity should also be evaluated.

Biotechnology

Varieties carrying special traits, such as herbicide resistance, are now available in Ontario. These may have value for growers trying to address specific weed problems or using certain tillage systems.

Planting and Crop Development

Seed Quality

Know the quality of the seed being planted. Certified seed has met purity and germination standards. The quality of common seed is not known unless it is germination tested before planting (see Appendix H, *Ontario Seed Laboratories Accredited by the Canadian Food Inspection Agency,* on page 263).

Seed Treatments

Seed treatments can be used to maintain seed quality in the days following planting and seedling health following germination. Canola seed should be treated with a combination of fungicide and insecticide. Fungicide is required to control seed-borne and early soil-borne diseases, especially blackleg, seed decay, damping-off and seedling blight. Insecticide controls flea beetles on emerging canola. Most seed is commercially treated. For more information on insecticide and fungicide options, refer to OMAFRA Publication 812, *Field Crop Protection Guide.*

Planting Date

Spring Canola

Seeding should be done as early as soil conditions permit. Canola is slightly less tolerant to spring frost and slower to establish than cereal crops. When seedlings emerge, the growing point is between the cotyledon leaves. Canola seedlings can recover from a frost that damages leaves, provided the growing point remains undamaged. The recommended planting time is from late April through early May. Yield reductions will occur if seeding is delayed. For fast germination, soil temperatures should be above 10°C (50°F).

Winter Canola

Seeding should be done August 15–30 (August 20–September 10 in Kent and Essex Counties). Seeding within these dates allows the canola plant to develop an adequate size root system (approximately 1.25 cm or $^1/_2$ in. diameter) to reduce the chances of frost heaving and desiccation in the spring. Delay beyond these dates greatly increases the risk of winterkill and is not recommended. If canola bolts in the fall, it will not survive through winter. Heavy competition from weeds or volunteer cereals in the fall can force canola growth, increasing chances of winterkill.

Emergence occurs 4–10 days after seeding. Seedlings emerge with the growing point above ground and between the cotyledons (seed leaves).

Row Width, Seeding Rates and Depth

Canola can be planted using grain drills, Brillion-type seeders or broadcasters. Seed at a rate of 4–5 kg/ha (3.5–4.5 lb/ac).

The most common method of planting is to use a seed drill that has been calibrated to plant in rows 18 cm (7 in.) wide and a seeding rate of 15–20 seeds/m of row (4–6 seeds/ ft). Planting depth should be set to 1–2 cm ($^7/_{16}$–1 in.) if there is adequate moisture and deeper if necessary to plant into moisture, but not deeper than 4 cm ($1^1/_2$ in.).

Broadcast Seeding

Broadcasting of canola seed is less common than in the past but can still be effective in some situations. Some growers are broadcasting canola seed directly onto frozen soil (frost seeding) with little or no tillage. Advantages of broadcast seeding are higher yield potential with an early seeding date, time saving and low cost. The major disadvantage of broadcasting is uneven planting depth. Frost injury is also a risk with an early seeding date. Good seedbed preparation before broadcasting followed by harrowing or packing will keep seed depth constant and ensure good seed to soil contact. Despite this, broadcast stands can be inconsistent in dry years. Seeding rates should be higher than when drilled (6–8 kg/ha or 5.3–7.1 lb/ac). Use seed-applied combinations of insecticides and fungicides when the seed is broadcast.

Seeding Conditions

A firm, level seedbed is the most important factor for even stand establishment and higher yields. Soils should be firm enough that heel marks are no deeper than the sole of a workboot. A firm seedbed will also help to hold moisture near the surface. A crumbly soil surface does not puddle and crust after a heavy rain. This is important because there is no opportunity to correct crusting. Packing before seeding can help to level and firm the seedbed, improving seeding depth control and reducing soil moisture loss. Packing after planting generally improves emergence and yield, particularly if the soil may dry out before emergence.

Crop Rotation Considerations

Use a four-year rotation with crops other than crucifers. Beware of planting canola adjacent to fields of previous canola, since air-borne spores may be released from old crop stubble for as long as 3–4 years. Avoid other broadleaf crops such as soybeans or sunflowers in the rotation since they are alternate hosts for white mould (Sclerotinia).

Note that some herbicides used in corn and soybeans can leave soil residues that may injure canola seedlings. Canola is particularly sensitive to herbicides such as triazine and ALS (Group 2) products. Some of these may be dependent on soil factors such as pH or organic matter. Consult the labels of herbicides used previously to note any restrictions before planting. See OMAFRA Publication 75, *Guide to Weed Control*, Herbicide Crop Rotation Restrictions Table 2.

Replant Decisions

Generally, canola plants in thin stands will branch out aggressively, resulting in no significant yield loss. A uniform stand of 10 plants/m^2 (1 plant/ft^3) will have a yield that is 90% of a full stand. Since canola responds to early planting, it is generally better to replant to a different crop if the original planting is unsuccessful.

Plant Development

Canola responds to well-drained fields with a minimum pH of 5.5. Canola can either self-pollinate or cross-pollinate depending on various environmental factors. Wind-blown pollen can travel up to 500 m (1,600 ft). Bees may carry pollen over 2 km (1.2 mi). Canola pollen drift from herbicide-tolerant varieties has been observed, causing genetic traits to "drift" from one field to another. Where the genetic purity of the canola seed is important, suitable isolation distances between fields should be allowed for.

Principal Growth Stages of Canola

Rosette

A rosette of leaves forms, with older leaves at the base increasing in size and smaller younger leaves developing in the centre. Leaf area development is directly related to growth rate and final yield.

Table 8-1.
Nitrogen Recommendations for Spring Canola

Price Ratio[1] ($/kg N:$/kg canola)	Area with 2,300 CHUs or less	Areas with more than 2,300 CHUs
	Nitrogen Rate (kg/ha)	
3.3	110	90
2.5	130	100
2.0	140	110
100kg/ha = 90 lb/ac		

[1] To use the table, the price of canola must be known or estimated. Canola at $350/t and nitrogen at $0.65/kg results in a price ratio of 1.9 (0.65 ÷ 0.35). At these prices, use about 140 kg/ha of nitrogen in an area with 2,300 CHUs or less.

Bud
Lengthening days and rising temperatures trigger bud formation in the centre of the rosette and rises as the stem rapidly "bolts." The main stem reaches 30%–60% of its final height at the start of flowering. A large leaf area (especially upper leaves) at this stage strongly influences pod set and final yield.

Flower
Flowering begins with the opening of the lowest bud on the main stem and continues upward on both main and secondary branches. Flowering continues for about 14–21 days. The maximum plant height is reached at peak flowering. Hot temperatures during flowering can cause heat blast and reduced yields (see Plate 138 on page 298).

Ripening
The leaf, stem and especially pod surface area are major food sources for the developing seed. Seed filling is complete about 30–40 days after flower opening. Pod ripening occurs from bottom to top of the plant.

Fertility

Placement and Timing

Most fertilizer for canola is broadcast. The high rates of nitrogen required and the seeding methods used work against the use of fertilizers banded with the seed. There may be occasions, particularly where phosphorus soil test levels are low, when phosphorus application with the seed would be advantageous. Take care not to exceed safe rates. The rate of nitrogen fertilizer placed with the seed must not exceed 11 kg/ha (10 lb/ac). Place only superphosphate or monoammonium (MAP) phosphate with the seed.

Table 8-2.
Spring Nitrogen Requirements for Winter Canola

Price Ratio[1] ($/kg N:$/kg canola)	Expected Yield[2] t/ha		
	2	3	4
	Most Profitable Nitrogen Application (kg N/ha)		
3.3	125	170	195
2.5	160	195	210
2.0	180	210	220
100 kg/ha = 90 lb/ac			

[1] To use this table, the price of canola must be known or estimated. Canola at $350/t and nitrogen at $0.65/kg results in a price ratio of 1.9 (0.65 ÷ 0.35). At these prices and an expected yield of 3.0 t/ha, use 210 kg/ha of nitrogen.

[2] 1 t/ha = 893 lb/ac

Nitrogen

Spring Canola

Canola has a tremendous demand for nitrogen. The nitrogen fertilizer recommendations for canola in Table 8-1, *Nitrogen Recommendations for Spring Canola*, left, are based on the price ratio between canola and nitrogen fertilizer. Rates should be adjusted downward if manure was applied or if the previous crop contained legumes such as alfalfa (see Table 2-15, *Adjustment of Nitrogen Requirement Where Crops Containing Legumes Are Plowed Down*, on page 36, and Table 2-16, *Average Amounts of Dry Matter, Nitrogen and Available Phosphate and Potash for Different Types of Organic Nutrient Sources*, on page 37). Excessive nitrogen in the soil has been linked to green seed problems.

Winter Canola

Fall Application
Apply up to 40 kg/ha (36 lb/ac) of nitrogen in the fall. If the land was fallowed for one or more months before planting or if forage legumes were plowed down or manure applied before planting, no nitrogen fertilizer should be applied.

Spring Application
The rate for spring application of nitrogen is based on the expected yield and on the price ratio between canola and nitrogen fertilizer. See Table 8-2, *Spring Nitrogen Requirements for Winter Canola*, above.

Phosphate and Potash

Phosphate and potash recommendations for canola are given in Table 8-3, *Phosphate and Potash Recommendations for Spring Canola Based on OMAFRA-*

Table 8-3.
Phosphate and Potash Recommendations for Spring Canola Based on OMAFRA-Accredited Soil Tests

Sodium Bicarbonate Phosphorus Soil Test (ppm)	Rating	Phosphate (P_2O_5)[1] Required (k/ha)	Ammonium Acetate Potassium Soil Test (ppm)	Rating	Potash (K_2O)[1] Required (kg/ha)
0-3	LOW	70	0-15	LOW	70
4-5		60	16-30		50
6-7		50	31-45		40
8-9		30	46-60		30
10-12	MEDIUM	20	61-80	MEDIUM	20
13-15		20	81-100		20
16-20	HIGH	0	101-120	HIGH	0
21-25		0	121-150	VERY HIGH	0
26-30		0	151-180		0
31-40	VERY HIGH	0	181-210		0
41-50		0	211-250		0
51-60		0	251 +	EXCESSIVE[2]	0
61 +	EXCESSIVE[2]	0			

100 kg/ha = 90 lb/ac

[1] Where manure is applied, reduce the fertilizer according to the amount and quality of manure (see the section *Manure*, on page 20).

[2] A rating of "Excessive" may mean reduced yield or quality of the crop.

Accredited Soil Tests, above. For information on the use of this table or if you do not have an OMAFRA-accredited soil test, see the section *Fertilizer Recommendations*, on page 31.

The phosphorus requirement for canola is greater than those for cereals, due to the higher protein content of the seed. A 2.5 t/ha (1 ton/ac) canola crop will remove on average 66 kg/ha (59 lb/ac) of phosphate fertilizer (P_2O_5). The germination and emergence of canola is quite sensitive to fertilizer salts, which can substantially reduce stands. Most of the research in Canada has shown a good response from an initial 11-17 kg/ha (10-15 lb/ac) of starter phosphate. The highest response can be expected on soils testing low to medium and when planting into cool soil conditions.

Nutrient Deficiencies

Sulphur

Canola requires approximately twice the amount of sulphur that cereal crops do. Soils in Southern and Northeastern Ontario generally have adequate sulphur, either as native soil sulphur or from atmospheric deposition, for optimum crop yields. Trials have shown no consistent response to sulphur containing fertilizers in Southern or Northeastern Ontario. There have been scattered instances of sulphur-deficient soils with low organic matter in Northwestern Ontario. Deficiency shows up in canola plants as a general yellowing of the entire plant.

Boron

Boron deficiencies are rare in canola. Symptoms include seed abortion, misshapen pods and narrow, strap-like leaves. It is seen very rarely, but when it occurs it can significantly reduce yields. Boron deficiency can be corrected with either foliar or soil applications of soluble boron fertilizers.

Harvest and Storage

The most common method of harvesting canola is swathing, followed by combining, but direct harvest is also used.

Direct Harvest

Direct combining is most successful when the crop's maturity and crop density are uniform, and the crop is relatively heavy, partially lodged and well knitted together. These conditions reduce the risk of shelling and pod drop due to wind. For direct-harvested canola, the crop is ripe when the pods rattle when shaken. Some varieties are less prone to shattering and are therefore well suited to direct combining. The need for and cost of using a desiccant should be evaluated versus swathing the crop. Seed oil content tends to be higher when a crop is direct harvested.

Swathing

Swathing at the correct stage of maturity reduces green seed and seed losses from shattering. The colour of the seed is more important than the overall colour of the field. When the seed reaches physiological maturity at 35%–40% moisture, it turns from green to yellow and then to a dark brown. The time to swath is when most of the yield in a field is ready. The optimum time to swath is when 30%–40% of the seeds in pods on the main stem have changed to red or brown.

The pods at the bottom of a canola plant ripen first, therefore the pods at top may still be greenish when the field is ready for harvest. Yield losses and quality reductions (lower oil content and green seeds) are significant if the crop is swathed prior to 10% seed colour change. Later swathing can result in excessive shattering of the seedpods. On larger acreage, if swathing is started at 25% colour change, then the maturity of acres can be swathed at near optimum maturity. Seed colour can quickly go from 10% to near 50% in a few days, under hot, dry weather.

Under hot (30°C or 86°F), dry conditions, swathing is not recommended. Swathing in the morning or evening results in slower plant dry-down. This lowers the chance of green seed and poor oil content.

Canola ripens and dries quickly in the swath. Usually 5–10 days of good drying weather will lower the moisture content to a point where the seeds in the upper pods of the plants are firm. Canola seed can drop by 1% moisture or more per hour in the swath. Many operators start combining when the seed is slightly above 10% moisture.

Swathing canola can be achieved using an open-throated swather. It often helps to swath when the crop is moist with dew or during a light drizzle. The stubble should be left tall enough to support the swath (and minimize combine wear) but cut low enough to leave stems on the plants for filling purposes.

Late in the season, if frost is forecasted and plants are not at optimum maturity, swathing at 10% seed colour change will minimize green seeds as a result of the frost. A field that has been swathed 3 days prior to a frost will have minimal damage.

Combining Canola Swaths

Seed moisture content and green seed count should be checked before starting to combine. Hot or windy weather can result in seed with moisture that indicates it is ready for combining, before it has had sufficient time to clear itself of green chlorophyll. Several dews or light rain help seed to clear the green colour. Under good drying conditions, moisture content drops rapidly and combining can begin at about 12% moisture. Most current combine manuals include instructions for canola. A belt pick-up is preferred. Wind adjustment is critical. Use just enough wind to float the straw and pods on the chaffer and shake the seeds out of the straw. On larger-capacity combines, running the combine full with partial wind and sieve openings allows more rapid travel. Good combine set-up will allow some pod-ends to come into the bin. A very clean sample likely means seed is being blown out the back of the combine.

Storage

Canola seed is sold on the basis of 10.5% moisture, but for safe storage it should be less than 10% moisture. The moisture level for storage depends on temperature. At 30°C (86°F), seed should be no more than 8% moisture. Because the seed is small, air does not easily move through large quantities of canola. If the seed is tough or damp, spread it out in shallow layers and check frequently for heating. Canola can also be dried in a grain drier using low temperatures, but fine screens are necessary to prevent leakage.

Weed Control

Critical Period for Weed Control

Control weeds early in the growth of the canola crop. Once canola crops are established, they tend to be very competitive with weeds. Studies have found that canola must be maintained weed free up to the four- to six-leaf stage. In winter canola, volunteer cereals can sometimes be a problem. If volunteer cereals or annual weed density are high, winter canola growth is forced. Forcing winter canola growth will cause it to winterkill.

Crop Losses Due to Weeds

Yield losses will vary with the weed species and density of the weed as well as timing of weed emergence. Later-emerging plants tend to be less competitive and produce fewer seeds per plant. Canola, once established, is more competitive with weeds than row crops such as corn or soybeans.

Research in Western Canada has shown that a 5% yield loss would require 2 wild oat plants/m^2, 2 volunteer barley plants/m^2, 4 volunteer spring wheat plants/m^2 or 100 green foxtail plants/m^2. Other studies in Ontario have shown that annual broadleaf weeds are relatively more competitive than annual grasses (see Table 3-26, *Percent Corn Yield Loss Due to Weeds at Known Populations*, on page 74, and Table 4-17, *Soybean Yield Loss Due to Weeds at Known Populations*, on page 115).

Integrated Weed Management

Weed control in the canola crop is influenced by:

- crop rotation
- row width
- plant population
- variety characteristics
- tillage practices

Growing canola crops gives the opportunity to control weeds in late summer, after harvest of the crop. However, weeds that are left to grow following canola harvest can result in a high return of weed seeds to the soil seed bank, creating weed problems in following crops. The timing of control practices following canola harvest for annual weeds will be earlier than for perennial weeds such as quackgrass from which seed production is minimal.

Crop rotations can be effective in reducing certain perennial weeds that may grow best in a particular crop. Use vigorous, high-quality seed to achieve uniform stands at the recommended plant populations to compete with the weeds. Early planting gives the crop a head start on weeds to assist with crop competition. Planting deep can delay emergence and favour the weeds.

Equipment can carry weed seeds from one field to another. Combines, tillage equipment and soil erosion can all transport weeds. Similarly, weeds can infest a field from manure application or other soil amendments. Proper sanitation and cleaning of equipment as well as maintenance of border areas all effect the long-term weed management in the field.

Refer to OMAFRA Publication 75, *Guide to Weed Control*, for more information, including herbicide products and rates.

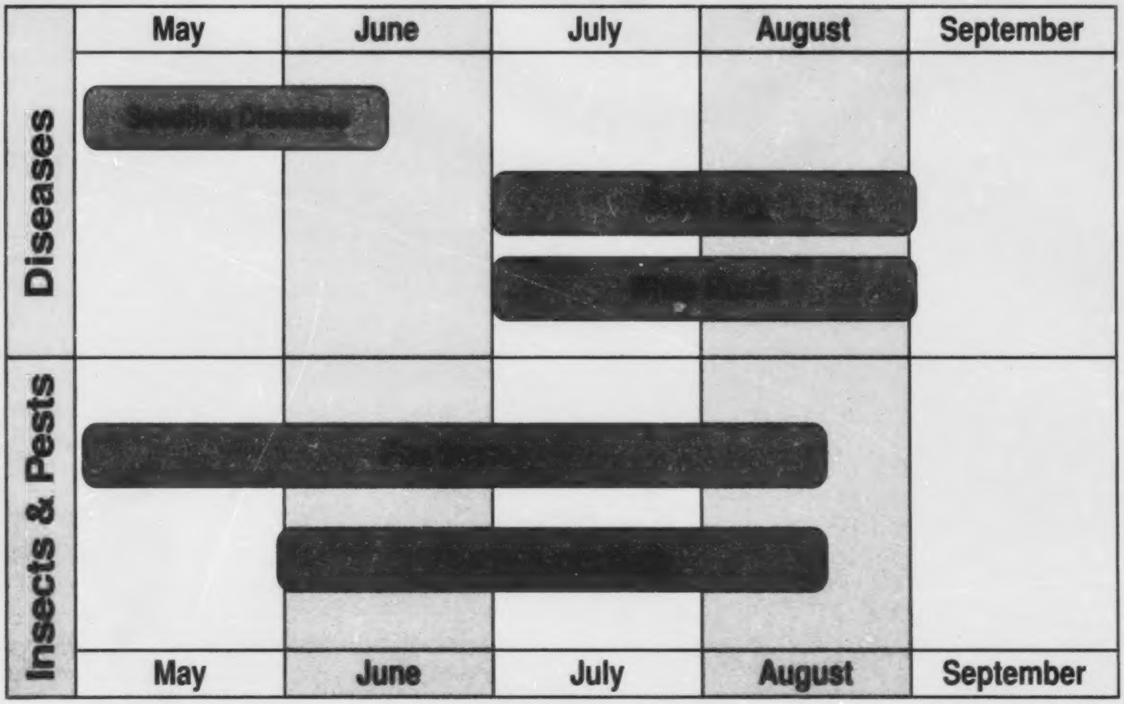

FIGURE 8-1.
Canola Scouting Calendar

Insects

Flea Beetle

Description. There are two species of flea beetles that attack canola. The striped flea beetle is approximately 1.5 mm long and has two cream-coloured strips along its back. The crucifer flea beetle is bluish-black, 1.5 mm long and does not have stripes (see Plate 139 on page 298). Flea beetles jump when disturbed, hence their common name. The larvae are white, approximately 3 mm in length and have brownish heads.

Life History. The adult beetle overwinters in sheltered areas such as woodlots under leaf litter. In early May, adults emerge and begin feeding on newly emerged canola seedlings. Hot, sunny weather promotes feeding damage. Eggs are laid on or in the soil between May and late June. Young larvae hatch and feed on the roots of the developing crop. Larval feeding occurs for approximately 1 month from June to late July. The larvae then pupate, and adults emerge in early August and feed on canola crops until late October. The adults then locate overwintering sites. There is one generation per year.

Damage. Both the adults and larvae feed on canola, however, it is the adult stage that is considered to cause damage. Damage is most severe during the initial 3 weeks following germination. Spring adults feed on the leaves of young seedling causing a shothole appearance. Leaves and plants eventually wilt and die. Stands become thinned, and plants may become stunted. High infestations can cause up to 50% yield reduction. Once the crop reaches the three- to four-leaf stage, the crop can withstand the damage. Fall adult feeding is usually not a concern except for in winter canola. Warm, dry weather promotes feeding.

Scouting Technique. Scout newly emerged canola fields every 2 days, especially along border rows, for the migration of overwintering adults from the fencerows and woodlots. Assess 10 plants in five locations across the field for feeding damage. Determine the average percentage of defoliation occurring. Monitor fields closely for pinhole feeding damage until the plants are past the four-leaf stage.

Action Threshold. Canola seedlings can withstand up to 25% defoliation in the cotyledon stage under good growing conditions without a significant reduction in yield. Seed treatments containing an insecticide are necessary at planting time to control flea beetles because of the difficulty in predicting their populations.

Management Strategies. Insecticide control methods should be directed against the beetle during the early stages of seedling growth Seed treatments are available, which can be followed by foliar-applied insecticides, should beetles attack the crop after the effect of the seed treatment is gone. Seed treatment insecticides differ in the length of control of flea beetles, so some products should be used in combination with a granular insecticide, which provides longer protection. A foliar application of insecticide may be required for flea beetle control if plant growth is slow and flea beetle populations high. If damage is isolated along border edges, spot treatments can be applied. Refer to OMAFRA Publication 812, *Field Crop Protection Guide,* for insecticide recommendations. Canola is a valuable foraging crop for honeybees. Avoid applying insecticides during bloom. Removing cruciferous weeds such as mustards along field borders will remove alternative food sources.

Diamondback Moth

Description. The adult is a small, light greyish-brown moth approximately 1 cm long (see Plate 140 on page 298). It is best identified by the white, diamond-shaped markings along its back when the wings are at rest. The larvae are light green-to-yellowish-green with a brown head and are approximately 8 mm long (see Plate 141 on page 299). Larvae will wiggle backward when disturbed or drop from the leaves on a silken thread.

Life History. Diamondback moths do not overwinter in Ontario but are carried in on southerly weather fronts in early May. There are three to four generations per year in Ontario. The adult moth typically lays her eggs on cruciferous weeds such as mustard as well as volunteer canola. Larvae hatch within a few days and create mines or tunnels in the leaf tissue. As the larvae develop, they begin to feed on the exterior leaf tissue. Larvae then pupate on the plant in cocoons and adult moths emerge within 2 weeks.

Damage. The main damage is caused by second-generation larvae, when plants are flowering and pod development begins. Young larvae feed on internal leaf tissue on the undersides of the leaf by creating small mines. More mature larvae, when numerous, will feed on the flowers and on the surface of young pods. Damaged pods do not fill correctly. Severe infestations cause the crop to appear white.

Scouting Technique. Examine 10 plants in five locations across the field twice weekly during the growing season. Gently pull out shot-holed plants and shake them on a piece of paper and count the number of larvae present.

Action Threshold. 200 to 300 larvae/m^2 (approximately two to three larvae per plant) at podding stage of canola. If infestation in the spring occurs very early in a late-planted canola field and the larvae feed on the developing buds, control may be necessary. At the early flowering stage, the action threshold is lower, and control is recommended when populations exceed 100–150/m^2 (one to two larvae per plant).

Management Strategies. Rescue treatments are available when populations reach thresholds. Refer to OMAFRA Publication 812, *Field Crop Protection Guide,* for insecticide recommendations. Canola is a valuable foraging crop for honeybees. Avoid applying insecticides during bloom. The adult diamondback moth population can be monitored using pheromone traps to warn of a possible infestation. Eliminate volunteer canola and cruciferous weeds that act as the initial food source for the spring generation. Cool, wet weather reduces moth flight activity, and adult females often die before laying their eggs. Humid weather following a rain helps promote the spread of a fungus that kills the larvae. Several predators and parasitic wasps also help to control this pest.

Diseases

Seedling Disease Complex

Incidence. Stand establishment is a major concern in canola production. Poor stand establishment is often due to seedling disease infection by one or more fungi; this is referred to as a "seedling disease complex." The primary fungi involved are *Rhizoctonia, Fusarium* and *Pythium*. The problem is greatest under cool conditions.

Appearance. Infection by these fungi or complex can exhibit many different symptoms. These include seed decay or rot, pre- and postemergence damping-off, seedling blight and seedling root rot. These symptoms occur during the first 4 weeks or by the fourth-leaf stage. Seeds may fail to germinate or die shortly after emergence. Seedlings that emerge may appear normal but can have significant root rot. Damping-off occurs when root decay or rot moves up the stem (hypocotyl) causing a girdling or pinching of the stem at or near the soil surface. The stem is weakened and is susceptible to breakage or toppling, where the characteristic reddish-brown lesions are formed. Infected seedlings often wilt or die when stressed because of a reduced (root pruning), constricted or rotted root system, especially under dry conditions. Stands are slow to emerge, thin or patchy. Yields can be reduced when stands are uneven or patchy. Severe plant loss may result in reseeding.

Disease Cycle. These fungi survive in the soil on decaying plant residues. Conditions that cause the developing seed or seedling to grow slowly are ideal for these fungi. The below-ground parts of the seedling harden (woody) at the two- to four-leaf stage and vigorously growing plants reach this stage quicker. At this stage, the seedlings are able to limit further infection and can regenerate roots quicker than they are lost. *Pythium* prefers cool, wet soils, whereas *Rhizoctonia* favours dry, light soils.

Management Strategies. Plant good quality seed into a firm, moist seedbed when the conditions are suited to promote rapid germination. Fungicide seed treatments will reduce infection and increase stand establishment. (Refer to OMAFRA Publication 812, *Field Crop Protection Guide.*) Maintain good fertility balance and avoid excess fertilizer, which promotes disease and phytotoxicities. Avoid deep planting of seed.

DISEASES

Blackleg

Incidence. Blackleg is a fungal disease that occurs in all canola-growing regions of Canada. In Western Canada, two strains (mild and virulent (severe)) of the fungus are found. As a result, substantial losses occur in Western Canada from the disease. In recent years, blackleg has been increasing in Ontario, especially in winter canola fields. Fortunately, the severe or virulent strain responsible for losses in the West has not been identified, to date, in Ontario.

Appearance. The first symptoms appear on the cotyledons or leaves as round-to-irregular (1–2 cm) white-to-buff lesions that contain numerous small black dots (pycnidia) (see Plate 142 on page 299). As the season progresses, the fungus may spread to the stem and crown of the plant, producing a canker that can girdle the stem (see Plate 143 on page 299). Severely infected plants ripen prematurely and have a black-to-grey discolouration at the base of the stem or crown. In severe cases, infected plants will lodge. Seeds of severely infected plants are small and shrivelled and may be infected with the fungus.

Disease Cycle. The blackleg fungus survives on canola residues (refuse) and on infected plants and seed. The fungus can be spread from field to field on canola refuse or diseased plants. The spores of the fungus are also spread by rain, wind and infected seed.

Management Strategies. Use less susceptible varieties. Most varieties are rated on a 1 (resistant) to 5 (highly susceptible) scale. Maintain a good crop rotation that has at least 3 years between canola crops. Fungicide seed treatments will reduce seed-borne infection and minimize the risk of introducing blackleg into new fields. However, the disease can still be spread from field to field on infected plants and refuse.

Refer to the OMAFRA Publication 812, *Field Crop Protection Guide,* for recommended seed treatment options.

White Mould (Sclerotinia Stem Rot)

Incidence: White mould is a canola disease that is sporadic within a region and varies greatly from year to year. This makes predicting disease potential or outbreaks very difficult. The disease is very destructive during periods of prolonged, wet weather. Losses of up to 50% can occur under ideal conditions.

Appearances. White mould is characterized by bleached stem lesions and hard black bodies (sclerotia) of white mould fungus inside the stems; it causes premature ripening of the plants (see Plate 144 and Plate 145 on page 299). The disease is often a problem when canola follows canola, white beans, soybeans or sunflowers. Infections that start on the dead blossoms spread to adjacent tissues, resulting in dead branches or dead plants. Plants may lodge. The rotted stems usually have a bleached appearance. Sclerotinia infections can be serious on canola if cool, wet weather occurs in the last 2 weeks of June and continues into early July when blossoming occurs.

Management Strategies. Use clean, certified seed and rotations of at least 4 years, including unaffected crops such as corn, wheat, barley or oats in fields with a history of Sclerotinia or white mould. During this rotation, it is necessary to avoid planting susceptible crops including mustard, sunflower, dry bean, soybean, field pea, lentil or garbanzo bean. At present, no resistant varieties exist. Keep fields clean of broad-leaved weeds since many are alternate hosts for this disease. Foliar fungicide treatments are effective but require scouting and precise timing. Refer to the OMAFRA Publication 812, *Field Crop Protection Guide,* for more information on recommended fungicide treatments.

Turnip Mosaic Virus

Incidence. Turnip mosaic virus (TuMV) has become a significant problem in some areas where winter canola is grown.

Disease Cycle and Appearance. Infestation takes place in the fall and causes leaf mottling (yellow or light green areas surrounded by normal green colour) and wrinkling or puckering of the leaf tissue between the veins (see Plate 146 on page 299). Spring growth is slow. Severely infected plants are stunted, twisted and generally light green or yellow. Pods are distorted and a significant proportion of the seeds are poorly filled. The disease appears to be more severe in areas where other cruciferous crops (such as rutabagas) are grown and in fields where pressure from weeds and volunteer cereals is high.

Management Strategies. Volunteer crops of winter canola often have high levels of TuMV infections. Early planting may be helpful in increasing the winter survival of the crop in some areas but appears to also increase the severity of TuMV where the disease is present. Only minor levels of TuMV infection have been observed in spring canola.

Other Crop Problems

Frost and Hail Damage

Canola seedlings can recover from a light spring frost if the growing point is not damaged. If hail removes both cotyledons or the stem is broken below the cotyledons, plants usually do not survive. A uniform stand of 10 plants/m^2 (1 plant/ft^2) will have a yield that is 90% of a full stand.

If hail occurs during vegetative growth, yield loss will be dependent on the amount of leaf area destroyed. Yield loss will equal approximately 25 % of the leaf area destroyed. Stem bruising and breakage will result in higher losses

If hail occurs during flowering, plants can compensate by developing secondary clusters and new branches (see Table 8-4, *Percentage Yield Loss Due to the Destruction of Branches During Flowering in Canola*, right). Yield losses will be highest when hail occurs during late flowering and during pod fill.

Table 8-4.
Percentage Yield Loss Due to the Destruction of Branches During Flowering in Canola[1]

% Branches Lost	Days From First Flower				
	-7	0	7	14	21
	Percentage Seed Yield Loss				
10	0	0	10	10	10
20	0	0	13	20	20
30	0	0	12	29	30
40	0	0	12	32	40
50	0	0	14	36	50
60	0	0	18	42	60
70	0	0	24	50	70
80	0	5	31	60	80
90	0	12	40	71	90
100	0	20	51	84	100

[1] Research conducted in Western Canada. Canola Council of Canada, 1994.

Herbicide Injury

Canola is highly susceptible to phenoxy herbicides. Clean spray equipment thoroughly before using on canola.

Winterkill

Winter canola is less winter-hardy than winter wheat in Ontario. Winterkill is most common in March and April after winter canola loses its winterhardiness, begins to grow and is then damaged by a reversion to extremely cold temperatures. Winterkill can also result from a lack of winter snow cover, prolonged periods of ice cover and desiccation by winter winds, resulting in reduced stands of winter canola. If the damage is severe enough (75% kill), the crop may not be salvageable. However, if 30% of the stand remains, with healthy plants evenly distributed across the field, the crop will compensate adequately.

OTHER CROP PROBLEMS

Cross-Pollination of Herbicide-Resistant Varieties

If varieties with different herbicide-resistant traits are allowed to cross-pollinate, the result may be volunteer plants with multiple resistance traits in subsequent crops. Separate fields planted to varieties resistant to different herbicides by a minimum of 175 m. This isolation will reduce the occurrence of field-to-field crossing.

Plugged Tile Drains

Sporadic problems with winter canola roots entering tile drains requires further investigation.

9. Other Crops

Buckwheat

Buckwheat is a fast-growing summer annual with broad, heart-shaped leaves and white flowers. It takes approximately 10–12 weeks from planting to harvest. It is frost sensitive and is usually planted later than other field crops.

Buckwheat is used for human consumption, as an ingredient in livestock feeds and as a source for buckwheat honey. It is also commonly used as a cover crop for weed suppression and green manure. The grain of buckwheat has an amino acid composition that includes lysine and thus provides a more complete protein compared to other cereals.

The most lucrative market is for the export of quality, large-seeded buckwheat to the Pacific-rim countries, particularly Japan.

Tillage Options and Seedbed Preparation

Frequently buckwheat is planted in abandoned fields, old pastures or other land that has been neglected for years. When preparing the seedbed, one should aim for effective weed control, conservation of moisture and a firm seedbed.

If the field was plowed in the fall, the soil should be disked in early spring, then disked or cultivated approximately 2 weeks later to kill weeds. This sequence can be repeated until seeding time.

Spring plowing is an option, however, be sure to plow as shallow as possible. To improve the soil condition and destroy weeds, work the soil every 7–10 days until seeding time. Shallow tillage minimizes new weeds coming to the surface and conserves moisture. Harrowing should leave the field ready for seeding.

If a hay or pasture is plowed in late-June or early-July, buckwheat can follow and be used as a cover crop to control weeds or to act as a green manure.

Field Selection

Buckwheat grows best on light-to-medium-textured soils but will grow on a wide range of soil types, producing a better crop on poor soil than any other grain. Buckwheat prefers well-drained soils with a pH of 5.0 to 7.0. It is intolerant of severely dry, saturated or compacted soils.

Buckwheat is adapted to a cool, moist climate but will also grow well during warm weather. It is sensitive to high temperatures and hot, dry winds. If these conditions occur during flowering, seed-set and yield will be reduced. Buckwheat is susceptible to late-spring and early-fall frosts and requires 10–12 weeks to reach maturity.

When growing buckwheat for seed, avoid planting in fields where other grains were previously grown, in order to reduce volunteer grain. This problem can be overcome by tilling in the fall and planting a winter cover crop that is incorporated in the spring before planting the buckwheat.

Weed control options in buckwheat are limited, so best yields will be obtained from clean, weed-free fields.

Also avoid fields that contain very high levels of nitrogen, since this can cause crop lodging. Often the lush growth associated with fields high in nitrogen has led to a higher incidence of white mould. White mould is a problem in soybeans, canola, sunflowers and buckwheat. If possible, avoid fields where white mould has been a problem.

Variety Selection

If the crop is being grown for export markets, variety selection becomes important. The Japanese, North American and European markets demand large-seeded varieties for milling and de-hulling purposes. Mancan is one popular variety that has a thick stem and medium height characteristics, which makes it more resistant to lodging.

New varieties tend to have larger seed size along with increased bushel weight. These large-seeded varieties have larger leaves, and as a result do not require higher seeding rates than the smaller-seeded types.

BUCKWHEAT

For cover crop seed sources, refer to Cover Crop Seed Suppliers at www.gov.on.ca/OMAFRA/english/crops.

Planting

Buckwheat will germinate at temperatures anywhere between 7°C and 40.5°C (44°F and 105°F), so the planting date can be any time after the risk of frost has passed.

Yields are highest if buckwheat is planted immediately after the risk of frost has passed. Where possible, try to avoid flowering in the very hot weather of midsummer. Early plantings help minimize volunteer problems the following year, however, in cold springs, some have experienced more weed problems with early plantings. In a cold spring, planting should be delayed until conditions are more favourable for crop emergence.

Traditionally, buckwheat was planted in mid-summer and often combined after frost. Although this method avoids flowering during hot weather, dropped seed reduces yield and poses a severe volunteer problem for the following crops.

Planting seeds with a grain drill will produce a more even stand, but satisfactory results can also be obtained with broadcast seeding. Plant seeds at a depth of 4-6 cm (1½-2½ in), in moist soils. Place seed only deep enough to reach consistently moist soil, to obtain rapid and uniform emergence. Seedlings should emerge in 2-5 days.

Recommended seeding rates for seed production are 50-65 kg/ha (45-60 lb/ac), which is equivalent to 1-1.25 bu/ac. This will achieve the ideal plant stand of 140-183 plants/m^2 (13-17 plants/ft^2).

When planting buckwheat for a green manure crop, the optimum seeding rate ranges from 0.054-0.108 t/ha (1-2 bu/ac). Higher seeding rates result in higher plant populations, producing a smothering effect for weed control. However, even if the stand is thin, the plant's ability to branch out will often compensate for the thinner stand and will still result in good weed control. When using the higher seeding rate, divide the seed in half and cross-plant the field with the grain drill. This appears to give better spacing of plants with fewer tall, thin stems and subsequent lodging problems.

Flowering begins 5-6 weeks after sowing and continues for at least 1 month. There are three flower sets with buckwheat. Insects, honeybees and leafcutter bees are the main pollinating agents and are essential for good seed set. An arrangement with an apiarist will be of mutual benefit.

As a Green Manure

Buckwheat has the reputation of using phosphate unavailable to other crops, thereby increasing the amount of phosphorus available to following crops. To take advantage of its large biomass, buckwheat is incorporated between 4 and 7 weeks after planting, before the first seeds have set. It is disked down at 10% bloom and left on the surface for a few days to dry. When plants start to crinkle when stepped on, it is time to be disked into the soil. If the field is left until full bloom, there is more likelihood of volunteer problems the following year. A second or even third planting may be possible in long growing seasons.

Fertility

Fertility requirements for buckwheat are similar to oats. Table 9-1, *Phosphate and Potash Recommendations for Buckwheat and Flax Based on OMAFRA-Accredited Soil Tests*, on page 245, and Table 9-2, *Nitrogen Requirements for Buckwheat Based on OMAFRA-Accredited Soil Tests*, on page 246, display the recommended rates of phosphate and potash and nitrogen based on OMAFRA-accredited soil tests.

Caution: *Buckwheat is prone to lodging with high soil nitrogen.*

Harvest and Storage

Harvest

Buckwheat is an indeterminate plant. Flowers, green seed and mature seed are present on the plant at the same time. Harvest must occur prior to the development of overripe seed. This will be approximately 10 weeks after planting. At this time, the crop is still growing and flowering, however 70%-75% of the seeds should be brown and mature and not yet dropping from the bottom of the bloom spike. If harvest is delayed until the seeds nearest the ground begin to fall, yields will be decreased due to seed dropping and the volunteer population will cause problems for the next crop. Yields will vary depending on pollination and weather conditions. Yields of 2.2 t/ha (40 bu/ac) are possible but 1.1-1.6 t/ha (20-30 bu/ac) are more commonly reported.

Desiccation weakens the stem and causes lodging. Do not desiccate buckwheat. Swathing should be done before combining if the crop has not been killed by frost. Swathing is best done early in the morning when the dew is present or in damp weather to help minimize losses due to shattered seed. Cut the buck-

Table 9-1.
Phosphate and Potash Recommendations for Buckwheat and Flax Based on OMAFRA-Accredited Soil Tests

Sodium Bicarbonate Phosphorus Soil Test (ppm)	Rating	Phosphate (P_2O_5)[1] Required (kg/ha)	Ammonium Acetate Potassium Soil Test (ppm)	Rating	Potash (K_2O)[1] Required (kg/ha)
0–3	LOW	70	0–15	LOW	70
4–5		60	16–30		50
6–7		50	31–45		40
8–9		30	46–60		30
10–12	MEDIUM	20	61–80	MEDIUM	20
13–15		20	81–100		20
16–30	HIGH	0	101–120	HIGH	0
31–60	VERY HIGH	0	121–250	VERY HIGH	0
61+	EXCESSIVE[1]	0	251+	EXCESSIVE[1]	0

100 kg/ha = 90 lb/ac

[1] No expected agronomic response from additional application of nutrients. Ratings of "Excessive" may result in reduced yield or affect nutrient balance in crops. For example, additional phosphorus application to a soil >60 ppm phosphorus could induce a zinc deficiency on soils low in zinc and might also increase the risk of nitrate movement into groundwater, while additional potash application to a field already > 250 ppm K soil test could induce magnesium deficiency on soils low in magnesium.

wheat, leaving a high stubble to facilitate drying. Leave it to dry until moisture in the seed head reaches 16%.

When combining, reduce the pick-up speed to match the ground speed so as to minimize shattering. The draper-type of pick-up causes less shattering than the drum-type. To minimize breakage, reduce the cylinder speed to one-third (600–800 rpm) that used for cereal grains and the concaves set to approximately 13–16 cm ($5\frac{1}{4}$–$6\frac{1}{2}$ in.) in the front and 9 mm ($\frac{3}{8}$ in.) in the rear. The upper sieve is set at 16 mm ($\frac{5}{8}$ in.) and the lower sieve at 8 mm ($\frac{5}{16}$ in.). If seed is dehulling, increase concave size or lower cylinder speed. The lower sieve can then be opened gradually to the setting that does not allow excess foreign material to pass through. Check that the wind blast is strong enough to remove the maximum amount of trash without blowing out clean grain.

When using a summer planting system, wait until 7–10 days after a light fall frost before direct combining. Keep the cut as high as possible and ground speed low to prevent overloading the combine. Pay attention to the amount of coarse material that is allowed to pass through so that only a minimum of seed enters the return. In this way, breakage will be reduced.

Storage

A moisture content of less than 16% is needed for safe storage. The Japanese market buys only freshly harvested buckwheat, so do not store seed to sell the following year and do not mix old and new crops. It is easy to detect the difference between previously stored and newly harvested buckwheat by the colour of the grain just under the hull. Old seed oxidizes, and the light green layer just under the hull in new seed gradually changes to reddish-brown during storage.

Livestock Feed

Buckwheat grain can be used for livestock feed on a limited inclusion in the ration. Buckwheat grain can be up to one-third of the grain concentrate portion of the beef or dairy ration. More recent swine feeding research with newer varieties of buckwheat found that the overall performance of growing-finishing pigs was comparable to pigs fed cereal grains. However, the price of buckwheat makes this not as economical as feeding cereals.

***Caution:** Feeding the fodder, whether fresh or dried, can have toxic effects. The primary toxic effect is a photosensitization in animals with light-coloured skin (this includes cattle, goats, sheep, swine and turkey) exposed to the sun. Jaundice is a secondary toxic effect.*

Weed Control

Weed control in buckwheat can be difficult and requires planning, since there are few herbicides available, particularly for broadleaf weed control. Since buckwheat is sown late, there is ample oppor-

Table 9-2.
Nitrogen Requirements for Buckwheat Based on OMAFRA-Accredited Soil Tests

Growing Region	Maximum Rate of Nitrogen for Buckwheat (kg/ha)
Southern Ontario	35
Northern Ontario	55

tunity to control problem weeds with herbicides or cultivation before seeding. Do not use residual herbicides (i.e., residues from the triazine, sulfonylurea and trifluralin herbicides) before seeding.

For current weed control options, refer to OMAFRA Publication 75, *Guide to Weed Control.*

Insects and Diseases

Buckwheat seldom has insects and diseases concerns.

Flax

Flaxseed has many uses. Its major use has traditionally been in oil-based paints and other protective coatings but it is also used in such things as linoleum, printer's ink, soaps, putty, industrial lubricant and as a salt-resistant coating for concrete highways and sidewalks. Flaxseed contains 35%–40% linseed oil. After oil extracting, the remaining linseed meal is used as a livestock protein supplement, averaging approximately 35% protein content. The addition of flax or flax byproducts in a variety of foods has diversified this market.

In recent years, the acreage of flax grown for oilseed markets has been quite limited in Ontario due to a lack of local crushing facilities. In the early 1950s, Ontario grew over 30,000 ha (74,100 ac) of flax but this has been reduced to less than 1,000 ha (2,470 ac) during the last decade. More recent promotion of the health benefits of flaxseed and of potential export markets for fibre flax may allow for a resurgence of this crop in Ontario in some areas. More information on this crop in Canada is available from the Flax Council of Canada Web site at www.flaxcouncil.ca.

Unless otherwise stated, the recommendations given here refer to oilseed type flax. Recommendations for fibre flax may be different, and more research may be needed for that crop.

Tillage

Conventional tillage is preferred. In most cases, this has been fall primary tillage followed by early spring tillage and planting. Secondary tillage should be shallow to set up a firm level seedbed. Packing either before or after planting is recommended. Crop success to date has been better where surface crop residues are low. Some growers have experimented with no-till planting with some success. Use rotations similar to those for cereals or legume forages.

Variety Selection

Variety selection will be different for oilseed markets than for fibre purposes. Until now, oilseed varieties have been the only commercially produced flax grown in Canada. Oilseed varieties are grown specifically for the oil extracted from the seed.

Solin is a new oilseed developed from flax using advanced crop-breeding techniques. Solin oil contains less than 5% linolenic acid (compared to the more than 50% contained in flaxseed oil), producing a light oil suitable for cooking. Canadian Grain Commission Standards specify that solin varieties must have a yellow seedcoat.

Currently there are no organized flax variety trials in Ontario, however flax and Solin variety trials results from Western Canada are available from the Flax Council of Canada Web site at www.flaxcouncil.ca.

Planting

Flax is planted using similar equipment to cereals in narrow rows (15–20 cm or 6–8 in. apart). Using a grain drill usually results in a more even seeding depth and plant emergence than broadcast seeding. Optimum seeding depth is 2.5–4.0 cm ($1–1^{1}/_{2}$ in.) deep (half to two-thirds of the depth for cereal grains). Optimum seeding rates are 35–50 kg/ha (31–45 lb/ac).

Sow as early as possible in the spring on a dry, firm seedbed. Early planting usually results in less injury due to weeds, insects and diseases and makes the crop easier to harvest. Well-drained loam, silt loam or clay loam soils are preferred. Performance has been noted to be poorer on sandy soils due to a limited root system that is susceptible to drought because of a relatively short taproot. Generally, seedlings can withstand moderate frost.

Crop Development

Flax is an annual plant with a short taproot from which fibrous roots grow to depths of approx. 1.2 m (4 ft) in light soil. The height of the crop varies from 45–91 cm (18–36 in.), depending on growing conditions. In thick stands, only a main stem develops but in thin stands four or more tillers can be produced. Flowers may be white, blue, pink or violet, depending on variety. Flowers open shortly after sunrise and drop by noon. Flax flowers for 3 weeks or more if sufficient nutrients are present. Its flowers can self-pollinate, but insects can cross-pollinate between varieties. A seed capsule produces up to 10 seeds ranging in colour between reddish or deep brown to smoky yellow. The seed has mucilaginous material, giving it a sticky texture when wet.

Fertility

Flax recommendations for nitrogen are the same as for mixed grain (45 kg/ha or 40 lb/ac in Southern Ontario and 70 kg/ha or 62 lb/ac in Northern Ontario). Excessive nitrogen will make the crop lodge. A soil test is the best method of determining fertilizer requirements. See Table 9–1, *Phosphate and Potash Recommendations for Buckwheat and Flax Based on OMAFRA-Accredited Soil Tests*, on page 245. Flaxseed is susceptible to fertilizer burn; all fertilizer should be broadcast.

Harvesting and Storage

Harvest

Flax typically yields about 1,200–2,000 kg/ha (1,100–1,800 lb/ac). Flaxseed can be harvested by either direct combining or by swathing prior to combining. Swathing, then combining, results in drier seed than direct combining. Swathing should be done when approximately 90% of leaves have fallen off, and the seeds have turned dark brown. Flaxseed doesn't shatter as easily as other grains. Weedy crops should be swathed to allow weeds and straw to dry out before harvest. Leave 15 cm (6 in.) of straw stubble in the field to keep windrows off the ground. Under good drying conditions, the crop can be combined 3–4 days after swathing.

Keep combine cutter bars and swathers clean and sharp to reduce immature flax accumulating on the knife. To prevent gumming of cutting parts, apply water or kerosene frequently. Combine flax when the straw is dry and seeds rattle in the boll. Early-sown flax is easier to thresh than late-sown flax because it has drier conditions to dry in before being harvested. Batt reels should be used when direct combining, because the pick-up reels cause problems with wrapping.

The general recommendation for combine adjustment is to close up the clearance between the cylinders and concave to about half that of cereal grains and slow down the cylinder. Be sure to plug any holes in the grain tank, augers and elevators, because flax seed is extremely slippery and will flow through small holes.

Where uneven maturity or weeds are considered to be a problem for harvesting, the crop can be sprayed with a chemical desiccant. Chemical desiccation or drying of the crop has numerous advantages:

- earlier harvesting
- elimination of the need for swathing
- reduction in combining time
- less wear on machinery
- cleaner seed
- reduction or elimination of the need for artificial drying

Desiccated flax should be harvested as soon as possible after it is ready, to avoid weathering.

Storage

Flax is not normally stored on the farm but is shipped immediately after harvest. Optimum moisture is 10.5%. Higher moisture percentages will incur a drying and shrinkage charge. Proper storage is critical since flax can spoil quickly. Storage bins must have all holes repaired since flax can leak through very small openings. Remove green weeds and weed seeds to reduce amount of dockage.

Straw Removal

Oilseed varieties of flax straw are not suitable for linen production because of the short fibres in the stem. The flax straw is slow to rot in the soil and can be a problem for tillage operations following harvest or in the following crop season. Flax straw is sometimes used in feedlots.

Weed Control

Flax is a poor competitor with weeds. Flax does not form a dense canopy to shade the ground and so allows weeds to establish. Flax should be planted in relatively weed-free fields whenever possible. Weed seeds in harvested grain result in dockage; weed seeds absorb oil from the flax seed.

For complete herbicide recommendations, refer to OMAFRA Publication 75, *Guide to Weed Control*.

Insects and Diseases

Insects and diseases are typically not a concern in flax production.

Sunflower

Sunflowers have been grown in Ontario for several decades. The main market for Ontario sunflowers has been for the birdseed and confectionery markets. Both black seeded and striped sunflower seeds are sold into the birdseed markets. There are no sunflower oilseed crushing markets in Ontario. Acreage in Ontario has varied from 500–1,000 ha (1,235–2,470 ac) per year during the past 10 years.

Tillage

Sunflowers require a firm, moist seedbed that is weed free. Conventional tillage is usually preferred over no-till, as the tillage is beneficial to control weeds.

The best crop performance is usually on medium-textured soils that are naturally well drained: loam, silty loam or silty clay loam. Sunflowers can also grow well on sandy soils, but yield will be reduced under drought conditions. Avoid poorly drained soils as they will delay planting, slow the rate of growth and cause a higher risk of disease.

Variety Selection

There are no sunflower variety trials conducted in Ontario. Variety testing is conducted through the National Sunflower Association of Canada at P.O. Box 382, Morden, MB, R6M 1A4.

Sunflowers can be classified as either oil or confectionery. Oil-type sunflowers have black hulls and can be conventional hybrids, dwarf hybrids, mid-oleic or open pollinated varieties. Dwarf hybrids mature 6–13 days earlier than conventional hybrids. Open pollinated sunflower (Sunola) varieties are shorter and require less heat to mature than normal sunflowers but they do not have good disease resistance.

Non-oil-type sunflowers have striped hulls and are grown for the human food market. Only the largest of the confection sunflowers are used for human consumption, but these varieties have little tolerance for bird or insect damage.

Hybrids have many advantages over open pollinated varieties. Hybrids have approximately 20% greater yield, better disease resistance (especially downy mildew, rust and Verticillium wilt), a high degree of self-compatibility, which reduces the need for bees to pollinate, and more uniform height and moisture content at harvest.

Sunflowers are tall, broad-leafed, usually single-stemmed plants, with one head per plant. The stem is hairy and becomes fibrous as the plant matures. Plants are heliotropic, which means that the heads face east by morning and west by evening, following the day's sun. They have a deep taproot system, which allows them to handle drought and access to deep water and nutrient supply that is generally unavailable for many other annual crops.

Planting

Sunflowers are usually planted in early May, similar to corn, and usually bloom in late July. They require approximately 100–120 days to mature. Seedlings are relatively tolerant to frost up to the four-leaf stage. A delay in planting beyond May 15 will increase the risk of frost damage prior to maturity in the fall. When delays in planting are unavoidable, use early-season hybrids/varieties.

Optimum planting depth is 3–5 cm (1¼–2 in.) and not more than 8 cm (3¼ in.), in moist soil. Shallow planting is suited to cold, wet, fine-textured soil. Sunflowers are prone to lodging in heavier soils or where there is heavy rain and wind.

The ideal row width is 60–90 cm (24–36 in.). Use a corn planter with appropriate seed adjustments or a grain drill with some of the runs plugged. Grain drills typically give poorer emergence.

The recommended seeding rate is 40,000–60,000 plants/ha (16,000–24,000 plants/ac). Confection sunflowers should not be seeded greater than 18,000 plants/ac, to help encourage large seed size. Plant 25% more seed than the desired plant population. Narrow row spacing (18–25 cm or 7–10 in.) and solid stands increase the risk of white mould with humid Ontario climate. Less lodging occurs if rows are planted east to west, as sunflower heads face to the east and cause plants to bend toward the east.

Rotation

Do not plant sunflowers in the same field more than once every 4–5 years, due to disease build-up. Canola, field beans, soybeans and buckwheat are also hosts of white mould (Sclerotinia); monitor rotations with these crop closely or avoid them altogether.

Volunteer sunflowers can also be a problem in some crop rotations. Sunflowers are sensitive to atrazine and other herbicide carryover, such as from some of the sulphonylurea (ALS) herbicides.

Fertility

The recommended amount of nitrogen for sunflowers is 90 kg/ha (80 lb/ac). The most efficient use of nitrogen is when most of the nitrogen fertilizer is applied as a side-dress before the plants are 30 cm (12 in.) tall. Test your soil to determine the phospho-

Table 9-3.
Phosphate and Potash Recommendations for Sunflowers Based on OMAFRA-Accredited Soil Tests

Sodium Bicarbonate Phosphorus Soil Test (ppm)	Rating	Phosphate (P_2O_5)[1] Required (kg/ha)	Ammonium Acetate PotassiumSoil Test (ppm)	Rating	Potash (K_2O)[1] Required (kg/ha)
0–3	LOW	110	0–15	LOW	170
4–5		100	16–30		160
6–7		90	31–45		140
8–9		70	46–60		110
10–12	MEDIUM	50	61–80	MEDIUM	80
13–15		20	81–100		50
16–30	HIGH	20	101–120	HIGH	30
31–60	VERY HIGH	0	121–250	VERY HIGH	0
61+	EXCESSIVE[1]	0	251+	EXCESSIVE[1]	0

100 kg/ha = 90 lb/ac

[1] No expected agronomic response from additional application of nutrients. Ratings of "Excessive" may result in reduced yield or affect nutrient balance in crops. For example, additional phosphorus application to a soil >60 ppm phosphorus could induce a zinc deficiency on soils low in zinc and might also increase the risk of nitrate movement into groundwater, while additional potash application to a field already > 250 ppm K soil test could induce magnesium deficiency on soils low in magnesium.

rous and potash requirements (see the section *Soil Testing*, on page 28). See Table 9-3, *Phosphate and Potash Recommendations for Sunflowers Based on OMAFRA-Accredited Soil Tests*, above.

Harvest and Storage

Harvest

Typical sunflower yields in Ontario range from 1,500–2,000 km/ha (1,300–1,800 lb/ac). Plants are ready for harvesting when the back of the heads turn yellow, and bracts around the head are brown, hard and dry. Seeds at this stage have approximately 50% moisture. Harvest is normally in September to mid-October.

In Ontario, if a crop is late maturing, drying will be facilitated by a killing frost. Use of a desiccant is therefore typically not required. However, early frost may reduce yield and oil content. To avoid this, harvest at a higher percentage moisture and dry seeds to reduce shatter loss and exposure to birds. Minimize the period between maturity and harvest to prevent bird damage and head rot.

Sunflowers are harvested with a combine equipped with a small grain head. Most combines are adapted with long seed-gathering pans extending in front of cutter bar to collect and salvage shattered seed. The reel is typically removed or raised for sunflower harvest. To prevent seed damage, use the slowest cylinder speeds with the largest openings. Reduce air flow to prevent seeds from being blown through the back.

Storage

After harvest, clean seed to remove trash. For proper storage, seed must contain 10% moisture or less. Dry higher moisture seed immediately after harvest. Sunflowers dry easily in conventional grain dryers. Confection types may wrinkle or be scorched. Allow to cool before storing.

Caution: Dry at low temperature because fine hairs and fibres from the seed coat could ignite when put through the drying fan.

In general, bins will hold 70% as much tonnage of sunflower as corn. They can be stored for short periods at 8.5%–12% moistures. Higher moisture or warm seeds may result in spoilage.

Weed Control

Sunflower seedlings suffer from weed competition. If weeds are not controlled early in the season, crop performance is reduced. As sunflowers mature, they become more able to compete with weeds.

The crop can be harrowed before seedling emergence to remove emerging weeds before they become established. A light spring tooth harrowing can be done when sunflower seedlings are between the four- and six-leaf stage to remove late-emerging weeds. Harrowing is best done under hot, dry conditions to reduce crop damage. Inter-row cultivation is also recommended.

For herbicide recommendations, refer to OMAFRA Publication 75, *Guide to Weed Control*.

Insects

Insects are typically not a problem in sunflowers.

Disease

White Mould (Sclerotinia)

White mould (Sclerotinia) can be a problem in sunflower production. Sclerotinia causes stalk rot (basal stem rot), midstem infections and head rot and leads to large yield reduction (see Plate 147 on page 300). The organism can live in the soil for long periods, so do not plant sunflower in rotation with susceptible crops, especially if these other crops demonstrated symptoms.

10. Stored Grain Management

Maintaining grain in good condition in storage requires careful, routine inspection and good storage practices. Good storage practices consist of more than simply putting good-quality grain into a weatherproof container.

Storing Grain in Bins

The quality of the grain loaded into storage is the best it will ever be. Over time, the quality of this grain will only decrease and seldom, if ever, improve. The goal is to maintain grain quality at the same level as when the grain went into the bin.

Good Bin Management Suggestions

- Treat empty bins to control any stored grain pests that may be living in cracks, crevices and below the aeration floor.
- Clean any grain going into a bin.
- Remove fines and other foreign material to reduce air flow restrictions and possibly reduce the risk of spoilage.
- Core a bin (augur out some grain) after filling to establish the flow funnel and redistribute the fines, even if the removed material is put back into the same bin.
- Install a manometer in the air plenum below the aeration floor to monitor the static pressure of the air moved by the fan. For information on how to build a manometer, see Appendix I, *Home-Built Manometer*, on page 265.
- Use the static pressure to determine the air flow of the fan, from the fan performance curve.
- Tightly cover aeration fan inlets when not in use, to prevent unintentional air movement through the grain.

Why Aerate Grain in Bins

The aeration of grain stored in a bin:

- removes field heat at the time of harvest or cools grain from a dryer
- brings the whole mass to a uniform temperature
- removes moisture that has respired from the stored grain as a result of temperature changes caused by the outside air

As bin surfaces are warmed or cooled by the sun or outside air, air currents start to move by convection in the grain mass. Moisture from the grain is carried by these convective air cells and condenses on colder surfaces. These colder areas may be inner bin surfaces or the grain itself. Spoilage can occur if this convective air movement is not arrested. Routine aeration of the bin contents will prevent convective air movement.

Maintain a temperature differential of no more 5°C between the grain mass and the average outside air temperature to prevent convective air movement from occurring.

Basics of Aeration

- Bring the whole grain mass to the same temperature.
- Operate the fan only when relative humidity levels will not add moisture to the grain.
- Operate the fan for enough hours to totally change the whole grain mass temperature, which may require a number of days.
- Become familiar with Equilibrium Moisture Content charts for the grain or beans you are storing (see the section *Harvest and Storage* in each commodity chapter). Run the fan only under outside conditions that will not add moisture to the stored product. Relative humidity levels of night-time air can add moisture to small grains, beans and natural air dried corn.
- See Table 10–1, *Time Required for Aeration Front to Move Through Grain*, on page 252, for the aeration time required to completely change the bin content temperature.

Grain Storage Monitoring

> If you have grain stored on your farm, monitor the bins on a routine schedule.

Bins storing the grain being used regularly for feed can be monitored as they're being used. Remember to check the bins that are not having grain removed on a routine basis. Grain can go out of condition quickly. By carefully and diligently monitoring stor-

Table 10–1.
Time Required for Aeration Front to Move Through Grain

Airflow Rate (CFM/bu)	Grain Cooling (hr)		
	Fall	Winter	Spring
1/20	300	400	240
1/10	150	200	120
1/5	75	100	60
1/4	60	80	48
1/3	45	61	36
1/2	30	40	24
3/4	20	27	16
1	15	20	12

CFM = cubic feet per minute; 1 CFM/bu = 13 L/sec/m^3

age bins, growers will be able to detect the warning signs of possible spoilage problems and be able to take appropriate action to prevent further reductions in quality.

Monthly Bin Monitoring Checklist

- Turn on your aeration fan.
- Climb up and look inside the bin. Look for signs of moisture on the underside of the roof. If water droplets or ice are present, aerate the bin. Moisture from the grain has been carried into the attic space and condensed on the roof metal.
- Run the aeration fan if a light dusting of snow has been driven into the top of a storage bin. It will sublimate and be discharged as harmless water vapour. If much greater amounts of snow are found, shovel it out.
- Check for any off-odours. The air should smell like clean grain.
- Check the grain surface to see if it looks the same as the last time. If it looks dull or off-colour, investigate further.
- Check for changes in the static pressure or the working pressure of the fan in the plenum under the aeration floor since last month. A decrease is no cause for concern. An increase, however, indicates that something has increased the resistance of the air as it moves through the grain mass. Investigate deeper into the grain mass.
- Look for any signs of insect activity.
- Record your notes in a monitoring logbook for comparison with the next months' readings.

Insect Management for Farm-Stored Grain

> The key to controlling insects in stored grain is prevention through good sanitation and storage practices.

The following strategies are essential for preventing infestations, reducing the need for rescue fumigation treatments.

Keep a Sanitary Facility

The most important strategy is to keep the facility insect free by cleaning bins and equipment before storing grain. Grain residues from previous crops are the main source of new infestations. At least 2 weeks before storing grain, ensure the facility is thoroughly cleaned and pest free by removing all grain residue, as well as caked material, using a good vacuum cleaner. Ensure that all old grain has been removed from cracks and crevices, behind partitions, between double walls, outside and under bins, in grain handling equipment, inside aeration piping and under perforated floors. Harvesting and grain handling equipment with old crop residues are a very important source of new infestations. Fully perforated floors are a problem because they cannot be lifted for cleaning, and grain dust will accumulate and may become infested.

Clean up all spills of grain and feed. Burn all residue grain that is removed, deposit it in a sanitary fill or grind it up for feed. Leave space between feed rooms and storage facilities because feed rooms are difficult to keep free of pests, which can quickly spread to nearby storage facilities.

Do not store grain in buildings that shelter animals or hay. Mangers, feed boxes and troughs are often infested with insects. These shelters are also warmer and provide an excellent wintering site for insects.

Maintain Sound Storage Facilities

After clean up, repair facilities so that they are pest-proof. Seal cracks and crevices that may allow insects to enter.

Store Clean, Dry Grain

Never store new grain with old grain, because insects will spread from the old grain to the new. Ensure that grain being placed in the storage facility is pest-free. Moulds as well as insects are much more troublesome in moist grain. If stored grain has more than 15% moisture, check it regularly. Wheat should be dried down to 12% moisture if you are planning to store it for longer than a month through the warm summer months. Corn should be dried to 14% moisture.

Monitor Storage Temperature Properly and Sample for Insects

Wheat is the most susceptible crop to infestations because it is harvested in the summer when insects are most active inside and outside the storage facilities. Once in the bin, the grain is still warm and can provide an excellent habitat for stored-grain insects. In Ontario, corn storage usually follows after wheat storage, and infestations can easily be carried from the wheat to the corn. Monitor the temperature of the grain using temperature sensors placed throughout the grain pile. Warm areas in the pile often indicate insect and/or spoilage problems.

Using aeration to cool down grain in the fall will reduce insect infestation and slow reproduction. Insects do not develop in grain with temperatures below 10°C (50°F) and can be killed if temperatures are kept below -10°C (50°F) for over 10 days. Rusty grain beetle and Indian meal moth can be monitored using plastic probe traps (see Plate 148 on page 300). These probe traps are very sensitive and will show an infestation well before it reaches the economic threshold. If rusty grain beetle or Indian meal moths are found, fumigate the grain.

Treat Empty Bins With Diatomaceous Earth

Diatomaceous earth is a non-toxic dust made from a silicone-dioxide mixture from prehistoric, marine diatoms. When in contact with insects, the diatomaceous earth absorbs the protective waxy coating on the insect, causing it to die from dehydration. Apply the product to the empty bin through aeration fans at least 2 weeks prior to grain storage. Apply it to the grain as well, as it is being augured into the bin or storage facility. Wear a protective mask when applying diatomaceous earth to avoid inhaling the dust. Refer to OMAFRA Publication 812, *Field Crop Protection Guide*, for detailed application and label information.

> Preventative insecticides are not a substitute for good storage sanitation practices.

If bin surfaces are dusty or covered with caked material, the spray will not penetrate and kill crawling insects. Malathion is no longer recommended for Indian meal moth control as this insect has acquired resistance and is frequently not controlled by this product.

Use Rescue Treatments When Necessary

Should an insect problem occur, fumigation might be necessary. Turning the grain may reduce a secondary pest problem to below economic damage. However, if rusty grain beetles or Indian meal moths are evident, the problem is serious. If webbing is found on the surface of the pile, rake and remove this layer before fumigating. For information on fumigants, see OMAFRA Publication 812, *Field Crop Protection Guide*. Fumigants may only be applied by a licensed exterminator. Remove livestock and poultry that are in the same building, especially if they are under the grain bin.

Identify Pests Properly

Stored-grain insects are not specific to one crop but can move and feed across commodities. It is important to know which insect pest you have in your facility. Proper identification and density assessment are important, because management strategies may differ depending on the pest. Proper identification will also help determine the source of infestation. Some insects are only incidental pests and may not cause economic loss.

Stored-Grain Insects

Scouting Technique for Stored Grain Insects

In the grain pile, place four plastic probe traps (see Plate 148 on page 300) halfway between the centre and edge of the bin, in an X pattern, with the centre of the bin as the centre point of the X. Place the traps about 5 cm (2 in.) below the grain surface. Retrieve and examine them at least once a month. These probe traps are very sensitive and will show an infestation well before it is economically threatening. If insects are present in probes, follow the management strategies listed in Table 10-2, *Insect Management Strategies for Farm-Stored Grain*, on page 254.

Table 10–2.
Insect Management Strategies for Farm-Stored Grain

Description	Life History	Damage	Management Strategies
Rusty Grain Beetle — see Plate 149 on page 300.			
• flat, reddish-brown beetle • approx. 2 mm (1/16 in.) long • antennae are as long or longer than its head and thorax combined • flies when temperatures are above 25°C (77°F) • Larvae are white, approx. 3 mm (1/8 in.) long, have two brown projections at the rear • moves easily through the whole grain pile because of its small size	• cold-tolerant • overwinters as an adult • lays up to 500 eggs on surface of kernels • larvae hatch in 3–5 days • larvae penetrate seed and pupate inside • adults emerge, leaving distinctive exit hole	• adult and larvae feed on germ and bran • feeds on cracked or sound grain • feeds throughout pile of grain • high infestations generate heat, causing grain to mould and spoil	• proper sanitation and monitoring practices • use treatment with diatomaceous earth to protect from re-infestation • refer to OMAFRA Publication 812, *Field Crop Protection Guide,* for insecticide and fumigant information
Indian Meal Moth — see Plate 150 on page 300.			
• **adult** approx. 12 mm (1/2 in.) long • "A-shaped" when wings are at rest • wings are grey, bottom half are bronzy • active in the evening • larvae grow to approx. 8 mm (3/8 in.) long • **larvae** range from pinkish-cream to pale yellow to pale green/yellow with black heads • larvae have three pairs of legs on thorax, five pairs of abdominal prolegs • mature larvae wander, looking for places to pupate	• can go through its entire life cycle in approximately 21–30 days under warm conditions • not cold-tolerant • temperature limits number of generations per year • females lay eggs on kernels of grain on pile surface • young larvae found in grain clumps (3–10 kernels) held together by silk	• adults do not feed or cause damage • larvae feed on germ and bran, leaving kernels with these missing • all stages of larvae spin webbing (increases as preparing to pupate) • typically stays on top of pile, no more than 50 cm (20 in.) deep • high populations result in a mat of grain with silks up to 50 cm (20 in.) deep	• moth is resistant to malathion • remove webbed layer of grain before fumigation • refer to OMAFRA Publication 812, *Field Crop Protection Guide,* for insecticide and fumigant information
Granary Weevil — see Plate 151 on page 300.			
• **adult** is a dark brown snout beetle • approx. 4 mm (3/16 in.) long • **larvae** are white, wrinkled and wingless, 4 mm (3/16 in.) long • larvae always found inside grain, only leave kernel as adults • only attacks cereal grains, not legumes • cannot fly • can be confused with rice weevil – on surface of thorax, the small pits are round rather than oval, cannot survive cold	• female lays eggs into holes in the grain created with her snout • cements holes shut • larvae develop inside grain • adults live up to 8 months	• adult and larvae feed on sound grain • larvae spend entire life in one kernel, feeding on endosperm • several larvae can be inside one kernel • leaves round exit holes when exits kernel as adult	• refer to OMAFRA Publication 812, *Field Crop Protection Guide,* for insecticide and fumigant information

Table 10–2.
Insect Management Strategies for Farm-Stored Grain (Continued)

Description	Life History	Damage	Management Strategies
Pea/Bean Weevils			
• two species that attack peas or beans • **damage** and larvae resemble that of granary weevil • **adults** are short and squat (3–4 mm or $^{1}/_{8}$–$^{3}/_{16}$ in.) • heads are tapered at front • usually tan coloured with faint longitudinal striping • **larvae** are creamy yellow coloured, legless, and have a brass-coloured head capsule		• pea weevils attack peas, bean weevils attack beans • adults lay eggs in maturing beans in field with no apparent visible damage • damage noticed when new adults emerge from seeds, leaving round holes	• monitor beans for damage in storage • react with a fumigation • sort beans visually to remove "picks" • heavily infested peas or beans can be fed to livestock • refer to OMAFRA Publication 812, *Field Crop Protection Guide*, for insecticide and fumigant information
Lesser Grain Borer — see Plate 152 on page 300.			
• **adult** is a brown-to-black beetle • approximately 2 mm ($^{1}/_{16}$ in.) long • cylindrical in shape • small numerous pits on surface of wings • adult identified by location of head • head is turned downward and covered by large hood (prothorax) • larvae are creamy-white, C-shaped, with a dark head tucked into the thorax • musty odour associated with this pest	• female borer lays eggs in cluster on surface of kernels • larvae hatches and bores into the kernel • completes development inside kernel	• pest may move into Ontario due to climate warming • adult and larvae cause damage to sound grain • bore irregularly shaped holes into the grain • leave only shell and powdery dust • adult and larvae enter and exit several grain kernels • several individuals may attack same kernel • also feed off grain dust	• advise provincial field crop entomologist if found • refer to OMAFRA Publication 812, *Field Crop Protection Guide*, for insecticide and fumigant information
Grain Lice			
• also known as psocids or book lice • **adults** are soft bodied • approximately 1–2 mm ($^{1}/_{32}$–$^{1}/_{16}$ in.) long • have large heads with long antennae • range from brown to white and often are opaque • can be winged or wingless • resemble aphids • **young** are smaller and slightly paler than adults	• incomplete metamorphosis (young nymphs resemble adults) • several generations • can multiply quickly under warm conditions	• not a direct pest of grain • secondary pest that feeds on grain dust and damaged kernels • can be seen running over pile when numerous — visually inspect grain surface for tiny, fast-moving insects • generally restricted to the top of the grain pile	• turning and cleaning the grain reduces populations • lice are found in damp conditions • lowering humidity lowers populations • refer to OMAFRA Publication 812, *Field Crop Protection Guide*, for insecticide and fumigant information

Table 10–2.
Insect Management Strategies for Farm-Stored Grain (Continued)

Description	Life History	Damage	Management Strategies
Mites			
• **adults** barely visible to the naked eye • approx. 0.5 mm ($^{1}/_{64}$ in.) long • rounded • eight-legged • yellowish-brown • **larvae** look like adults but have six legs • two nymphal stages look similar to adult with four pairs of legs		• incidental insect on grain going out of condition • prefers damp grain • feeds on grain dusts and moulds	• keep grain dry and in good condition • refer to OMAFRA Publication 812, *Field Crop Protection Guide,* for insecticide and fumigant information

11. Appendices

Appendix A.
Insect-Monitoring Equipment Supply Companies

BioQuip Products
17803 LaSalle Avenue
Gardena, CA
U.S. 90248-3602

Tel: (310) 324-0620
Fax (310) 324-7931
Web site: www.bioquip.com

Gempler's Inc.
100 Countryside Dr.
P.O. Box 270
Belleville, WI
U.S. 53508

Tel: (800) 382-8473
Fax: (800) 551-1128
Web site: www.gemplers.com/

Great Lakes IPM
10220 Church Road, NE
Vestaburg, MI
U.S. 48891

Tel: (517) 268-5693
Fax: (517) 268-5311
Web site: www.greatlakesipm.com/

Quebec Insectes (Atelier Jean Paquet)
3, rue du Coteau
P.O. Box 953
Pont-Rouge, Quebec
Canada G3H 2E1

Tel/fax: (418) 873-2984
Web site: www.quebecinsectes.com/pages/english

Note: Inclusion in this list does not imply any endorsement or recommendation by the Ontario Ministry of Agriculture, Food and Rural Affairs.

Appendix B.
Accredited Soil-Testing Laboratories in Ontario

The following labs are accredited to perform soil tests for pH, buffer pH, P, K, Mg and Nitrate-N on Ontario soils.

Laboratory Name	Address	Telephone/Fax/E-mail	Contact
A & L Canada Laboratories East. Inc. Web site: www.al-labs-can.com	2136 Jetstream Rd. LONDON, Ont. N5V 3P5	Tel: (519) 457-2575 Fax: (519) 457-2664 E-mail: aginfo@al-labs-can.com	Mr. Greg Patterson Mr. Ian McLachlin
Accutest Laboratories Web site: www.accutestlabs.com	146 Colonnade Rd. Unit #8 NEPEAN, Ont. K2E 7Y1	Tel: (613) 727-5692 Fax: (613) 727-5222 Email: phaulena@accutestlabs.com	Mrs. Lorna Wilson Mr. Peter Haulena
Agri-Food Laboratories Web site: www.agtest.com	503 Imperial Rd. Unit #1 GUELPH, Ont. N1H 6T9	Tel: (519) 837-1600 1-800-265-7175 Fax: (519) 837-1242 Email: lab@agtest.com	Mr. Dale Cowan Ms. Nora Wilson
Soil and Nutrient Laboratory[1]	University of Guelph P.O. Box 3650 95 Stone Rd. W. GUELPH, Ont. N1H 2W1	Tel: (519) 767-6226 Fax: (519) 767-6240 E-mail: info@lsd.uoguelph.ca	Ms. Virginia Kerslake
Stratford Agri Analysis (A Daco Laboratories Ltd.)	1131 Erie St. Box 760 STRATFORD, Ont. N5A 6W1	Tel: (519) 273-4411 1-800-323-9089 Fax: (519) 273-4411 E-mail: info@stratfordagri.com	Mr. Dale Peters Mr. Gary Roberts Mr. Keith Lemp Dr. Jim Brimner

There is no official accreditation in Ontario for tissue analysis, but all the accredited soil-testing labs are monitored for proficiency on tissue analyses.

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[1] Formerly Analytical Services, Land Resource Science.

Appendix C.
Phosphorus Index

The Phosphorus Index evaluates erosion potential as well as application rate and placement of all phosphorus sources. This indicates the risk of off-site movement, while the proximity to a watercourse dictates the risk of off-site movement actually causing contamination of surface water. The final result of the phosphorus index calculation is a set of application rate restrictions at various distances from a watercourse. Tables A through E, below, provide the values needed to determine the Phosphorus Index.

Phosphorus Index to Assess Risk of Surface Water Contamination

From Table A		From Table B		From Table C		From Table D		From Table E		Phosphorous Index
	+		+		+		+		=	

Example Calculation

From Table A		From Table B		From Table C		From Table D		From Table E		Phosphorous Index
corn no-till planted on a 3% slope		clay loam soil on a 3% slope		P soil test of 35 ppm		10 kg/ha (9 lb/ac), placed with planter		143 kg/ha (128 lb/ac) of P_2O_5 applied in manure, incorporated 3 days		
2	+	4	+	8	+	2.5	+	7	=	23.5

Table A. Soil Erosion Value[1]

Slope within 150 m (500 ft) of watercourse	Length of Slope m (ft)	Hay	Other Crops			
			Up & Down Slope		Cross Slope	
			Plow	No-Till	Plow	No-Till
Flat (< 0.5%)	All	2	4	2	4	2
Gentle (0.5%–2%)	Short: 60 m (200 ft)	2	4	2	4	2
Gentle (0.5%–2%)	Long: 480 m (1,600 ft)	2	16	4	16	2
Moderate (2%–5%)	Short: 60 m (200 ft)	2	16	2	8	2
Moderate (2%–5%)	Long: 480 m (1,600 ft)	2	16	8	16	4
Steep (>5%)	Short: 60 m (200 ft)	2	16	4	16	4
Steep (>5%)	Long: 480 m (1,600 ft)	2	16	16	16	16

[1] **Note:** These values simulate a worst case scenario of soybeans on very fine sand in a high rainfall area. To obtain more accurate results using the universal soil loss equation refer to the nutrient management computer program (NMAN).

Table B. Water Run-off Value

Slope	Soil Texture			
	Sand	Loam	Clay Loam	Clay
Flat (1%)	1	1	2	4
Gentle (3%)	1	2	4	8
Moderate (5%)	1	2	4	8
Steep (8%)	2	4	8	8

Table C. P Soil Test Value

P Soil Test	Factor
< 15 ppm	2
15–30 ppm	4
31–60 ppm	8
61–100 ppm	16
> 100 ppm	32

Table D. P_2O_5 Fertilizer Value

Rate (Line K) kg/ha (lb/ac)	Method			
	Placed with Planter	Incorporated <2 weeks	Incorporated >2 weeks	Not Incorporated
None	0	0	0	0
<50 (<45)	2.5	4	7	13
50–75 (45–67)	3.5	5	8	14
>75 (>67)	5.5	7	10	16

Table E. P_2O_5 Manure Value

Rate (Line C) kg/ha (lb/ac)	Method			
	Injected	Incorporated <5 days	Not Incorporated Crop Cover	Not Incorporated Bare Soil
None	0	0	0	0
<37 (<33)	2.5	4	7	13
37–57 (33–54)	3.5	5	8	14
>57 (>54)	5.5	7	10	16

Once the Phosphorus Index is calculated, it is possible to outline restrictions to application rates and locations. Because the main risk from phosphorus pollution is to surface water, higher Phosphorous Index values will mean that a greater separation distance is required from surface waters for manure or broadcast fertilizer applications. The zone where application rates are restricted to crop removal is also increased. Application restrictions are outlined in Table F, right.

Table F. Application Restrictions at Various Phosphorus Index Values

P. Index	Separation Distance			
	<3 m (<10 ft)	3–30 m (10–100 ft)	30–60 m (100–200 ft)	>60m (>200 ft)
< 30		*Caution!*	No additional restriction due to Phosphorous Index	
30–50		Only apply P_2O_5 up to crop removal (Line M # 0)		
>50	*STOP!*	No application		

Source: Nutrient Management Practices BMP

Note: For a more detailed analysis of the Phosphorus Index, refer to the Nutrient Management Computer Program (NMAN) or the OMAFRA Factsheet, *Determining the Phosphorus Index for a Field*, Order No. 98-079.

Appendix D.
Calculating Available Nutrients from a Manure Analysis

Information from a manure analysis, plus knowledge of the conditions at the time the manure was applied, can be used to provide a more precise estimate of the available nutrients in the manure applied to your fields.

Available nitrogen is determined by subtracting the ammonia losses to the air from the ammonium-N applied, and adding the mineralization from the organic N portion of the manure.

Reductions in fertilizer phosphate and potash can be calculated by determining the available portion of the total P and K in the manure (40% for phosphorus and 90% for potassium) and multiplying by a factor to convert from the elemental form to the oxide form (fertilizer nutrients are expressed in the oxide form). Read the report carefully, since some labs make these conversions and report the nutrients available to replace fertilizer, while others report the elemental P and K in the manure.

The required calculations are summarized in the following table. The calculations will be the same whether the units are in percentage, lb/1,000 gal, or kg/tonne. Be sure to keep the same units throughout the calculation. Some reports will provide ammonium-N contents in ppm (mg/kg, mg/L), while the other numbers are in percentages. To convert ppm to percentage, divide by 10,000.

Available Nitrogen		**Available Phosphate**		**Available Potash**	
A. Total Nitrogen		H. Total Phosphorus (P)		K. Total Potassium (K)	
B. Ammonium-N		I. Available P (H x 0.4)		L. Available Potassium (K x 0.9)	
C. Organic N (A-B)		J. Available Phosphate (I X 2.29)		M. Available Potash (L x 1.2)	
D. Ammonium Losses (B x factor from Table 2-11, on page 32)					
E. Available Ammonium (B-D)					
F. Available Organic N (C x factor from Table 2-12, on page 33)					
G. Total Available N (E+F)					

For example, a manure analysis is received for a liquid dairy manure, with dry matter content of 7%, total N of 0.65%, ammonium-N of 3,500 mg/L, P of 0.6%, and total K of 0.3%. All the nutrient contents are expressed as percentage of wet weight.

The manure is applied in spring immediately before planting under warm, dry conditions and is incorporated 3 days after application.

The ammonium-N content can be converted to percentage by dividing by 10,000, giving an ammonium-N content of 0.35%. The organic N content can then be calculated by subtracting the ammonium-N from the total N (0.65 - 0.35 = 0.3% organic N).

Ammonium losses in this situation will be calculated as ammonium-N (0.35%) times the factor from Table 2-11, *Lime Requirements to Correct Soil Acidity Based on Soil pH and Soil Buffer pH,* on page 32, for the application conditions (0.65), giving an ammonium loss of 0.2275 (0.35 x 0.65 = 0.2275). The ammonium-N available to the crop is the initial ammonium-N minus the loss (0.35 - 0.2275 = 0.1225).

The available nitrogen from the organic portion is calculated as the organic-N times the availability factor in Table 2-12, *Example Calculation of the Fineness Rating of a Limestone,* on page 33. For liquid dairy manure, this is 0.2, so the available organic N is 0.06% (0.3% x 0.2 = 0.06%).

Total available N is the ammonium-N plus organic-N, giving a total of 0.1825% (0.1225 + 0.06 = 0.1825). This percentage of available N times the manure application rate provides the amount of nitrogen available to the crop from the manure application. To convert the percentage of nutrient to kg/tonne, multiply times 10 (to lb/1,000 gal, multiply times 100).

Available phosphate is the phosphorus content (0.6%) times the availability factor (0.4), times the conversion to phosphate (2.29). This gives an available phosphate from this manure of 0.275% (0.6% x 0.4 x 2.29 = 0.275%).

Available potash is the potassium content (0.3%) times the availability factor (0.9) times the conversion to potash (1.2). This gives an available potash from this manure of 0.324% (0.3% x 0.9 x 1.2 = 0.324%).

Appendix E:
European Corn Borer Economic Threshold Calculations

Calculations for UNIVOLTINE Threshold
(if profitable to treat a field)

Plants with shotholes_____/total plants checked____= ______(A)

Unfurl one of the shotholed plants from each location and look for live larvae

Multiply the average number of live larvae/unfurled plant ____ times (A) ____from above, which gives you live larvae/plant___(B).

(Example: 25 shotholed plants/100 plants = .25 =(A).If there are an average of 1.5 live larvae/unfurled plant, 1.5 x .25 = .38 = (B))

We figure there is about 5% yield loss/live larvae. Therefore, (B) from above times 5% is equal to your potential, percent yield loss _____(C).

Multiply ____(C) times your expected yield _____t/ha (or bu/ac) times value/tonne (or bu) = $____ (D). This is your loss potential in dollars.

Multiply _____(D) times expected effectiveness of a pesticide treatment (suggest 75%) and you arrive at the preventable loss in dollars/ha (or ac) $_______.

Compare your preventable loss to the cost of application plus pesticide and you will see if the treatment is cost effective.

Calculations for BIVOLTINE Threshold
(if profitable to treat a field)

________ number of egg masses/plant x 2borer/egg mass* = borers/plant (cumulative counts, taken 7 days apart)

________borers/plant x ____4 ___ % loss/borer** = ________ % yield loss

________% yield loss x _______ expected yield = _________ t/ha (or bu/ac) loss

________t/ha (or bu/ac) loss x $________ price/bu = $___________ loss/hectare (or acre)

$_______loss/hectare (acre) x ___75___% ***control = $_______ preventable loss/hectare (or acre)

$_______preventable loss/hectare (acre) – $________ cost of control/hectare (or acre) =___________

$_______gain (+) or loss (–) per acre if treatment is applied

*Assumes survival rates of two borers per egg mass; may vary with weather and egg mass size.

** Use 3% loss per borer per plant if infestation occurs after silks are brown. The potential economic benefits of treatments decline rapidly if infestations occur after the corn reaches the blister stage.

*** 75% is an average, use another value if desired.

Appendix F.
Laboratories Equipped for Feed Testing

Agribrands Purina Canada Inc.
127 Zimmerman Street South
P.O. Box 303
Strathroy, Ontario
N7G 3W3
Tel (519) 245-2690
Fax (519) 245-6089

Agri-Food Laboratories
Unit #1
503 Imperial Road North
Guelph, Ontario
N1H 6T9
Tel (519) 837-1600 or 1-800-265-7175
Fax (519) 837-1242

Animal Health Laboratory
Laboratory Services Division
Box 3612
Building 49, McIntosh Lane
University of Guelph
Guelph, Ontario
N1H 6R8
Tel (519) 824-4120, ext. 4502
Fax (519) 767-6240

Quality Swine Co-op
P.O. Box 53
Shedden, Ontario
N0L 2E0
Tel (519) 764-2300 or 1-800-265-4369
Fax (519) 764-2604

Shur-Gain
600 James Street South
St. Marys, Ontario
N4X 1C7
Tel (519) 349-2152 or 1-800-265-8507
Fax (519) 349-2159

Stratford Agri-Analysis
P.O. Box 760
1131 Erie Street
Stratford, Ontario
N5A 6W1
Tel (519) 273-4411 or 1-800-323-9089
Fax (519) 273-4411

Appendix G.
Soybean Cyst Nematode–Testing Laboratories

A & L Labs Canada East Inc.
2136 Jetstream Road
London, Ontario N5V 3P5
Tel (519) 457-2575
Fax (519) 457-2664

Agri-Food Laboratories
503 Imperial Road, Unit #1
Guelph, Ontario N1H 6T9
Tel (519) 837-1600 or 1-800-265-7175
Fax (519) 837-1242

Pest Diagnostic Clinic
Laboratory Services Division
University of Guelph
95 Stone Road West
Guelph, Ontario N1H 8J7
Tel (519) 767-6256
Fax (519) 767-6240

Contact these labs for current prices and nematode handling and shipping procedures.

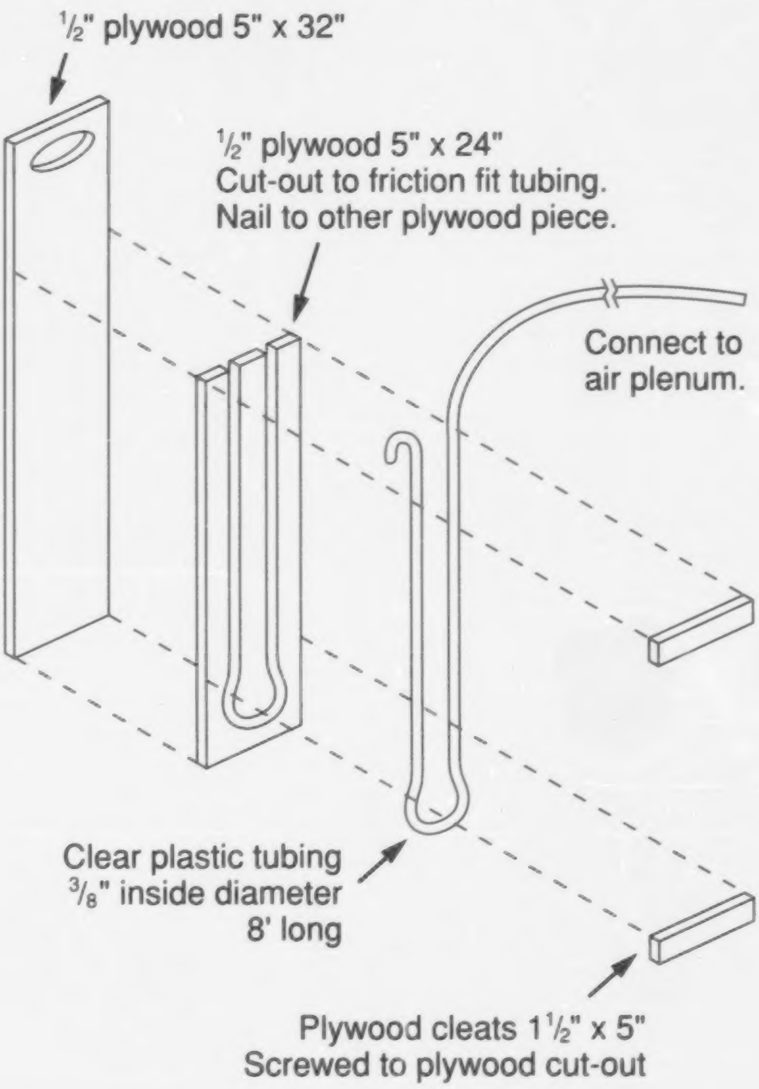
Appendix H.
Ontario Seed Laboratories Accredited by the Canadian Food Inspection Agency

			Scope of Accreditation			
Lab Name and Address	**Responsible Analyst**	**Phone & Fax**	**Purity**	**Germination**	**Disease**	**In-House Only**
AgReliant Genetics Inc. Seed Testing Laboratory P.O. Box 1088 Chatham, ON N7M 5L6	Ernestine Demers	Tel (519) 354-3210 Fax (519) 354-8155	Crop kinds in grade tables 1–6 and 18	Crop kinds in grade tables 1–7 and 18	None	x
Canadian Seed Laboratories Ltd. P.O. Box 217 208 St. David St. Lindsay, ON K9V 5Z4	Catharine Breadner	Tel (705) 328-1648 Fax (705) 324-2550	All crop kinds	All crop kinds	Soybean for *Diaporthe spp.* Pulses for *Ascochyta spp.* Barley and wheat for loose smut	
Dekalb Canada Inc. 301 Richmond St. Chatham, ON N7M 1P5	Bill Rodgers	Tel (519) 352-5310 Fax (519) 352-6259	None	Corn and soybeans	None	x
Fairlea Seeds Laboratory Services R.R. # 8 St. Thomas, ON N5P 3T3	Diane Dubois	Tel (519) 631-1369 Fax (519) 631-3358	None	Wheat, barley, oats, cereal mixtures, corn, soybeans, beans and peas	None	
First Line Seeds Ltd. R.R. #2 Guelph, ON N1H 6H8	Milena Jungbolt	Tel (519) 821-0882 Fax (519) 821-9755	Crop kinds in grade tables 1–6 and 18	Crop kinds in grade tables 1–6 and 18	None	x
Hardy Seed Ltd. R.R. # 1 Inkerman, ON K0E 1J0	Grahame Hardy	Tel (613) 989-2054 Fax (613) 989-3849	None	Wheat, oats, barley, beans, peas and soybeans	None	
Kent Agri Laboratory R.R. # 2 Tupperville, ON N0P 2M0	Dianne Gilhuly	Tel (519) 627-3737 Fax (519) 627-3737	All crop kinds	All crop kinds	None	
Lang Germination Lab 6 Clarinda St. P.O. Box 419 Teeswater, ON N0G 2S0	Shelley Lang	Tel (519) 392-8203 Fax (519) 392-8203	None	Crop kinds in grade tables 1, 2, 3, 5, 6 and 18	None	
Livingstone Seed Laboratory P.O. Box 27050 Postal Outlet 500 Rexdale Blvd. Etobicoke, ON M9W 6L0	Gail Livingstone	Tel (416) 743-7191 Fax (416) 743-7191	Crop kinds in grade tables 1–11 (except orchardgrass), 13–20	Crop kinds in grade tables 1–11 (except orchardgrass), 13–20	None	

Appendix H.
Ontario Seed Laboratories Accredited by the Canadian Food Inspection Agency (Continued)

Lab Name and Address	Responsible Analyst	Phone & Fax	Scope of Accreditation			
			Purity	Germination	Disease	In-House Only
Miller Seed Farm R.R. # 2 Bath, ON K0H 1G0	Michael MacKinnon	Tel (613) 352-7453 Fax (613) 352-7453	None	Wheat, barley, oats, cereal mixtures and soybeans	None	
Perth Seed Laboratory R.R. # 5 Mitchell, ON N0K 1N0	Bernadine Wolfe	Tel (519) 348-9057 Fax (519) 348-8165	Crop kinds in grade tables 1-6 and 18	Crop kinds in grade tables 1-6 and 18	None	
Pickseed Canada Inc. Seed Testing Laboratory P.O. Box 304 Lindsay, ON K9V 4S3	Kazi K. Alam	Tel (705) 878-9240 Fax (705) 878-9249	All crop kinds in grade tables 1–20	All crop kinds in grade tables 1–20	None	x
Pioneer Hi Bred Ltd. P.O. Box 730 #2 Highway West Chatham, ON N7M 5L1	Mary Ellen Van Zelst	Tel (519) 352-6350 Fax (519) 436-6741	Crop kinds in grade tables 1–5 (sunflower, safflower, corn) and grade table 7	Crop kinds in grade tables 1–7 and 18	None	x (own customers)
W.G. Thompson and Sons Ltd. P.O. Box 130 Blenheim, ON N0P 1A0	Christine DeRooy	Tel (519) 676-8146 Fax (519) 676-5674	None	Wheat, barley, oats, beans, soybeans and corn	None	
Vogel Seed Testing Laboratory 3995 Lafleur Road R.R. # 2 Apple Hill, ON K0C 1B0	Linda Vogel	Tel (613) 528-4045 Fax (613) 528-1048	None	Crop kinds in grade tables 1–6 and 18	None	

Appendix I.
Home-Built Manometer


½" plywood 5" x 32"
½" plywood 5" x 24"
Cut-out to friction fit tubing.
Nail to other plywood piece.
Connect to air plenum.
Clear plastic tubing
³/₈" inside diameter
8' long
Plywood cleats 1½" x 5"
Screwed to plywood cut-out

Source: Helmut Spieser, OMAFRA Ridgetown.

Appendix J.
Seeding Information

Crop	Seeding Rate	Seed Weight	
	kg/ha	kg/hl	lb/bu
Wheat (winter & spring)	100–130	75	60
Oats	60–110	42	34
Barley (winter & spring)	80–160	60	48
Rye	70–95	70	56
Triticale	75–100	65	52
Corn (field)	11–22	70	56
White Beans (70-cm rows)	40–45	75	60
Soybeans	65–155	75	60
Peas (field)	130–200	75	60
Buckwheat	55	60	48
Flax	40	70	56
Canola (spring & winter)	45	62	50
Millet (proso)	40	70	56
Sunflower oilseed	4	34	27
Sunflower stripes	6	30	24
Mustard (yellow)	8–11	70	56
Sudangrass	14	50	40
Sorghum	14	70	56
Annual canarygrass	35	62	50
Lupins	150–180	75	60

Appendix K.
Approximate Test Weights and Moisture Contents for Trade of Commercial Grains

Grain	% Moisture	lb/bu	kg/hl	g/0.5L
Barley	14.8	48	63.0	303
Buckwheat	16.0	52	58.0	285
Canola	10.0	50	–	–
Corn	15.5	56	66.0	333
Flax seed	10.0	56	65.0	305
Oats	13.5	34	51.0	235
Rye	14.0	56	72.0	349
Soybeans	14.0	60	70.0	357
Sunflowers (confectionary)	9.5	24	31.0	–
Sunflowers (oil)	9.5	27	35.0	–
Wheat	14.5	60	75.0	365

Appendix L.
Diagnostic Service

Samples for disease diagnosis, insect or weed identification, nematodes counts and *Verticillium* testing can be sent to:

Pest Diagnostic Clinic
Laboratory Services Division
University of Guelph
95 Stone Rd. W.,
Guelph, Ont., N1H 8J7
Tel: (519) 767-6256
Fax: (519) 767-6240
E-mail: pdc@lsd.uoguelph.ca

Payment must accompany samples at time of submission. Charges will be applied to each sample submitted.

SUBMISSION FORMS ARE AVAILABLE AT: www.uoguelph.ca/pdc

Fee Schedule	
Procedures	**Price/Sample**
Plant Diseases	
Diagnosis not requiring plating	$25
Diagnosis requiring plating	$40
Turf diagnosis	$50
Bacterial identification using Biolog	$95
Detection of virus using Transmission Electron Microscopy	$85
Detection of virus using ELISA (turnaround time = 5 working days. Bulk rates are available)	$60
Weed Identification	**$40**
Insects	
Basic identification	$25
Identification requiring dissection and/or extensive keys	$40
Nematode and Verticillium Counts	**Price/Sample**
Nematodes extracted from soil (Bearman Pan Method)	$25
Soybean cyst nematode & egg count	$35
Nematodes extracted from roots	$60
Verticillium count	$60

Turnaround Time:
Nematodes extracted from soil takes 7 or 8 days.
Nematodes extracted from roots takes 15 days.
Cyst count takes 3 or 4 days.

Payment: Please make cheque payable to the University of Guelph. VISA and Mastercard are also accepted. Please do not mail cash.

How to Sample for Nematodes

Soil

When to Sample

Soil and root samples can be taken at any time of the year, whenever the soil is not frozen. In Ontario, nematode soil population levels are generally at their highest in May-June and again in September-October.

How to Sample Soil

Samples should be taken with a soil sampling tube, trowel or narrow-bladed shovel. Soil should be sampled to a depth of 20–25 cm (8–10 in). If the soil is bare, the top 2 cm (1 in.) should be removed prior to sampling.. A sample should consist of 10 or more subsamples combined. Mix well. Then take a sample of $^{1}/_{2}$–1 L (1 pint to 1 quart) from this. No one sample should represent more than 2.5 ha (6.25 ac.)

Subsamples should be mixed in a clean pail or plastic bag.

Sampling Pattern

If living crop plants are present in the sample area, samples should be taken within the row and from the area of the feeder root zone (with trees this is the drip line).

Number of Subsamples

Based on the total area sampled

500 m^2 (5,400 ft^2)	10 subsamples
500 m^2–0.5 ha (5,400 ft^2–1.25 ac.)	25 subsamples
0.5–2.5 ha (1.25–6.25 ac.)	50 subsamples

Roots

For small plants, sample the entire root system plus adhering soil. For large plants, 10–20 g ($^{1}/_{2}$–1 oz.) fresh weight should be dug from the feeder root zone and submitted.

Problem Areas

Take soil and root samples from the margins of the problem area where the plants are still living. If possible, also take samples from healthy areas in the same field. If possible, take both soil and root samples from problem and healthy areas in the same field.

Sample Handling

Soil Samples:
Place in plastic bags as soon as possible after collecting.

Root Samples:
Place in plastic bags and cover with moist soil from the sample area.

Storage:
Samples should be stored between 5°C and 10°C (40°F and 50°F) and should not be exposed to direct sunlight or extreme heat or cold (freezing). **Only living nematodes can be counted. Accurate counts are dependent on proper handling of samples**

Submitting Plant for Disease Diagnosis or Identification

Sample Submission Forms

Forms can be obtained from your local OMAFRA office. Carefully fill in all of the categories on the form. In the space provided, draw the most obvious symptom and the pattern of the disease in the field. It is important to include the cropping history of the area for the past 3 years and this year's pesticide use records.

Choose a complete, representative sample showing early symptoms. Submit as much of the plant as is practical, including the root system, or several plants showing a range of symptoms. For turfgrass, submit a 10–15 cm, square piece of turf, including thatch, and at least 5 cm of soil. The sample should be taken from the outside edge of a ring or patch and include healthy and unhealthy turf and the interface between. If symptoms are general, collect the sample from an area where they are of intermediate severity. **Completely dead material is usually inadequate for diagnosis.** Plant specimens submitted for identification should at least include a 20–25-cm sample of the top portion of the stem with lateral buds, leaves, flowers or fruits in identifiable condition. Wrap plants in newspaper and put in a plastic bag. Tie the root system off in a separate plastic bag to avoid drying out and soil contaminating the leaves. **DO NOT** add moisture, as this encourages decay in transit. Cushion specimens and pack in a sturdy box to avoid damage during shipping. Avoid leaving specimens to bake or freeze in a vehicle or in a location where they could deteriorate.

Delivery

Delivery to the Pest Diagnostic Clinic should be made as soon as possible by first class mail or by courier at the beginning of the week.

Submitting Insect Specimens for Identification

Collecting Samples

Dead, hard-bodied insects and spiders should be placed in vials or boxes and cushioned with tissues or cotton. Soft-bodied insects and caterpillars should be placed in vials containing alcohol. Do not use water as this will result in rot. Do not tape insects to paper or send them loose in an envelope.

Live insects should be placed in a container with enough plant "food" to support them during transit. Be sure to write "live" on the outside of the container.

Appendix M.
Other Contacts

University of Guelph
Main Campus
Guelph, N1G 2W1
(519) 824-4120
www.uoguelph.ca

Alfred College
Alfred, K0B 1A0
(613) 679-2218
www.alfredc.uoguelph.ca/

Kemptville College
Kemptville, K0G 1J0
(613) 258-8336
www.kemptvillec.uoguelph.ca

Ridgetown College
Ridgetown, N0P 2C0
(519) 674-1500
www.ridgetownc.on.ca

Department of Plant Agriculture
www.plant.uoguelph.ca

Department of Plant Agriculture, Kettleby
1125 Woodchopper's Lane
R.R. # 1, Kettleby, L0G 1J0
(905) 775-3783

Department of Plant Agriculture , Simcoe
Box 587 Blue Line Rd.
Simcoe, N3Y 4N5
(519) 426-7127

Department of Plant Agriculture, Vineland
Box 7000, 4890 Victoria Ave. N.
Vineland Station, L0R 2E0
(905) 562-4141

Lab Services Division
www.uoguelph.ca/labserv/
Pesticide and Trace Contaminants
P.O.Box 3650
95 Stone Road West
Guelph, N1H 8J7
(519) 767-6200

Pest Diagnostic Clinic
(519) 767-6256

Agriculture & Agri-food Canada
Research Centres
Eastern Cereals and Oilseeds Research Centre
960 Carling Avenue
Ottawa, K1A 0C6
(613) 759-1952
http://res2agr.ca/ecorc/welcome.htm

Greenhouse and Processing Crops Research Centre
Harrow N0R 1G0
(519) 738-2251
http://res2.agr.ca/harrow/

Southern Crop Protection and Food Research Centre
1391 Sandford St., London N5V 4T3
(519) 457-1470
http://res2.agr.ca/london/pmrc/pmrchome.html

Vineland Research Farm
4902 Victoria Ave. N., Vineland
(905) 562-4113

Delhi Research Farm
Box 186, Schafer Rd., Delhi N4B 2W9
(519) 582-1950

Canadian Food Inspection Agency
www.cifa-acia.agr.ca
Regional Offices (Plant Protection)
Belleville
345 College Street East, Belleville K8N 5S7
(613) 969-3333

Hamilton
709 Main St. W. 101, Hamilton, L8S 1A2
(905) 572-4152

London
457 Richmond St., Suite 404, London, N6A 3E3
(519) 645-4021

Niagara Falls
(Mail address:)
R.R #1 P.O. Box #7, Niagara on the Lake, L0S 1J0

(Street address:)
14154 Niagara River Pkwy, Unit # 5, Niagara on the Lake
(905) 262-5331

Brantford
Federal Building, Dalhousie & Queen St, P.O. Box 637
Brantford N3T 5P9
(519) 751-8157

Ottawa District
3 Observatory Crescent, Bldg., #3 Central
Experimental Farm, Ottawa K1A 0C9
(613) 759-1571

Toronto Office
401 Champagne Drive, Unit 1, Downsview, M3J 2C6
(416) 954-1714

Windsor
441 University Ave. W., Suite 208, Windsor N9A 5P9
(519) 252-7095

Appendix N. The Metric System

Metric Units

Linear Measures (length)

10 millimetres (mm)	=	1 centimetre (cm)
100 centimetres (cm)	=	1 metre (m)
1,000 metres (m)	=	1 kilometre (km)

Square Measures (area)

100 m x 100 m = 10,000 m^2	=	1 hectare (ha)
100 hectares	=	1 square kilometre (km^2)

Cubic Measures (volume)

Dry Measure

1,000 cubic millimetres (mm^3)	=	1 cubic centimetre (cm^3)
1,000,000 cubic centimetres (cm^3)	=	1 cubic metre (m^3)

Liquid Measure

1,000 millilitres (mL)	=	1 litre (L)
100 litres (L)	=	1 hectolitre (hL)

Weight-Volume Equivalents (for water)

(1.00 kg) 1,000 grams	=	1 litre (1.00 L)
(0.50 kg) 500 grams	=	500 millilitres (0.50 L)
(0.10 kg) 100 grams	=	100 millilitres (0.10 L)
(0.01 kg) 10 grams	=	10 millilitres (0.01 L)
(0.001 kg) 1 grams	=	1 millilitre (0.001 L)

Weight Measures

1,000 milligrams (mg)	=	1 gram (g)
1,000 grams (g)	=	1 kilogram (kg)
1,000 kilograms (kg)	=	1 tonne (t)
1 milligram/kilogram	=	1 part per million (ppm)

Dry-Liquid Equivalents

1 cubic centimetre (cm^3)	=	1 millilitre (mL)
1 cubic metre (m^3)	=	1,000 litres (L)

Application Rate Conversions

Metric to Imperial or US (Approximate)

litres per hectare x 0.09	=	gallons per acre
litres per hectare x 0.11	=	*US gallons per acre*
litres per hectare x 0.36	=	quarts per acre
litres per hectare x 0.36	=	*US quarts per acre*
litres per hectare x 0.71	=	pints per acre
litres per hectare x 0.86	=	*US pints per acre*
millilitres per hectare x 0.015	=	fluid ounces per acre
grams per hectare x 0.015	=	ounces per acre
kilograms per hectare x 0.89	=	pounds per acre
tonnes per hectare x 0.45	=	tons per acre

Imperial or US to Metric (Approximate)

gallons per acre x 11.23	=	litres per hectare (L/ha)
gallons US per acre x 9.35	=	*litres per hectare (L/ha)*
quarts per acre x 2.8	=	litres per hectare (L/ha)
quarts US per acre x 2.34	=	*litres per hectare (L/ha)*
pints per acre x 1.4	=	litres per hectare (L/ha)
pints US per acre x 1.17	=	*litres per hectare (L/ha)*
fluid ounces per acre x 70	=	millilitres per hectare (mL/ha)
fluid ounces US per acre x 73	=	*millilitres per hectare (mL/ha)*
tons per acre x 2.24	=	tonnes per hectare (t/ha)
pounds per acre x 1.12	=	kilograms per hectare (kg/ha)
pounds per acre x 0.45	=	*kilograms per acre(kg/ac)*
ounces per acre x 70	=	grams per hectare (g/ha)

Fertilizer Conversions

K_2O	x	0.83	=	K (elemental)
P_2O_5	x	0.44	=	P (elemental)
Phosphorus (P)	x	2.29	=	P_2O_5
Potash (K_2O)	x	0.83	=	Potassium (K)
Potassium (K)	x	1.2	=	Potash (K_2O)

Metric Conversions

5 mL	=	1 tsp
15 mL	=	1 tbsp
28.5 mL	=	1 fl. oz

Dry Weight Equivalents

Metric		Imperial
100 grams/hectare (g/ha)	=	1½ ounces/acre (oz/ac)
200 grams/hectare (g/ha)	=	3 ounces/acre (oz/ac)
300 grams/hectare (g/ha)	=	4¼ ounces/acre (oz/ac)
500 grams/hectare (g/ha)	=	7 ounces/acre (oz/ac)
700 grams/hectare (g/ha)	=	10 ounces/acre (oz/ac)
1.10 kilograms/hectare (kg/ha)	=	1 pound/acre (lb/ac)
1.50 kilograms/hectare (kg/ha)	=	1¼ pounds/acre (lb/ac)
2.00 kilograms/hectare (kg/ha)	=	1¾ pounds/acre (lb/ac)
2.50 kilograms/hectare (kg/ha)	=	2¼ pounds/acre (lb/ac)
3.25 kilograms/hectare (kg/ha)	=	3 pounds/acre (lb/ac)
4.00 kilograms/hectare (kg/ha)	=	3½ pounds/acre (lb/ac)
5.00 kilograms/hectare (kg/ha)	=	4½ pounds/acre (lb/ac)
6.00 kilograms/hectare (kg/ha)	=	5¼ pounds/acre (lb/ac)
7.50 kilograms/hectare (kg/ha)	=	6¾ pounds/acre (lb/ac)
9.00 kilograms/hectare (kg/ha)	=	8 pounds/acre (lb/ac)
11.00 kilograms/hectare (kg/ha)	=	10 pounds/acre (lb/ac)
13.00 kilograms/hectare (kg/ha)	=	11½ pounds/acre (lb/ac)
15.00 kilograms/hectare (kg/ha)	=	13½ pounds/acre (lb/ac)

Liquid Equivalents

Litres/Hectare		Approximate Gallons/Acre
50	=	5
100	=	10
150	=	15
200	=	20
250	=	25
300	=	30

Speed

miles per hour	x 88	=	feet per minute
miles per hour	x 1.467	=	feet per second
miles per minute	x 88	=	feet per second
miles per minute	x 60	=	miles per hour
feet per minute	x 0.01667	=	feet per second
feet per minute	x 0.01136	=	miles per hour
feet per second	x 18.288	=	metres per minute
feet per second	x 0.3048	=	metres per second
feet per second	x 1.09728	=	kilometres per hour
centimetres per second	x 1.968504	=	feet per minute
centimetres per second	x 0.0328084	=	feet per second
centimetres per second	x 0.02236936	=	miles per hour
kilometres per hour	x 27.777778	=	centimetres per second
kilometres per hour	x 3280.8399	=	feet per hour
kilometres per hour	x 54.680665	=	feet per minute
kilometres per hour	x 0.6213712	=	miles per hour
miles per hour	x 1.6093439	=	kilometres per hour

Abbreviations

%	= per cent (by weight)	km/h	= kilometres per hour
ai	= active ingredient	kPa	= kilopascal
AP	= agricultural powder	L	= litre
cm	= centimetre	m	= metre
cm^2	= square centimetre	m/sec	= metres per second
DG	= dispersible granular	m^2	= square metre
DP	= dispersible powder	mL	= millilitre
E	= emulsifiable	mm	= millimetre
e. g.	= for example	SC	= sprayable concentrate
EC	= emulsifiable concentrate	SP	= soluble powder
F	= flowable	t	= tonne
g	= gram	W	= wettable (powder)
Gr	= granules, granular	WDG	= water dispersible granular
ha	= hectare	WP	= wettable powder
kg	= kilogram	km/h	= kilometres per hour

Conversion Tables — Metric to Imperial

Length		
1 millimetre (mm)	=	0.04 inch (in.)
1 centimetre (cm)	=	0.40 inch (in.)
1 metre (m)	=	39.40 inches (in.)
1 metre (m)	=	3.28 feet (ft)
1 metre (m)	=	1.09 yards (yd)
1 kilometre (km)	=	0.62 mile (mi)
Area		
1 square centimetre (cm^2)	=	0.16 square inch (in^2)
1 square metre (m^2)	=	10.77 square feet (ft^2)
1 square metre (m^2)	=	1.20 square yards (yd^2)
1 square kilometre (km^2)	=	0.39 square mile (mi^2)
1 hectare (ha)	=	107,636 square feet (ft^2)
1 hectare (ha)	=	2.5 acres (ac)
Volume (dry)		
1 cubic centimetre (cm^3)	=	0.061 cubic inch ($in.^3$)
1 cubic metre (m3)	=	1.31 cubic yards (yd^3)
1 cubic metre (m^3)	=	35.31 cubic feet (ft^3)
1,000 cubic metres (m^3)	=	0.81 acre-foot
1 hectolitre (hL)	=	2.8 bushels (bu)
Volume (liquid)		
1 millilitre (mL)	=	0.035 fluid ounce (Imp)
1 litre (L)	=	1.76 pints (Imp)
1 litre (L)	=	0.88 quart (Imp)
1 litre (L)	=	0.22 Imperial gallons (gal)
1 litre (L)	=	0.26 U.S. gallon (U.S. gal)
Weight		
1 gram (g)	=	0.035 ounce (oz.)
1 kilogram (kg)	=	2.21 pounds (lb)
1 tonne (t)	=	1.10 short tons
1 tonne (t)	=	2,205 pounds (lb)
Pressure		
1 kilopascal (kPa)	=	0.15 pounds/square inch ($lb/in.^2$)
Speed		
1 metre per second (m/sec)	=	3.28 feet per second (ft/sec)
1 metre per second (m/sec)	=	2.24 miles per hour (mph)
1 kilometre per hour (km/h)	=	0.62 mile per hour (mph)
Temperature		
°F	=	$(°C \times {}^9/_5) + 32$

Conversion Tables — Imperial to Metric

Length		
1 inch (in.)	=	2.54 centimetres (cm)
1 foot (ft)	=	0.30 metre (m)
1 yard (yd)	=	0.91 metre (m)
1 mile (mi)	=	1.61 kilometre (km)
Area		
1 square foot (ft^2)	=	0.09 square metres (m^2)
1 square yard (yd^2)	=	0.84 metre (m^2)
1 acre (ac)	=	0.40 hectare (ha)
Volume (dry)		
1 cubic yard (yd^3)	=	0.76 cubic metre (m^3)
1 bushel (bu)	=	36.37 litres (L)
Volume (liquid)		
1 fluid ounce (Imp.)	=	28.41 millilitres (mL)
1 pint (Imp.)	=	0.57 litre (L)
1 gallon (Imp.)	=	4.55 litres (L)
1 gallon (U.S.)	=	3.79 litres (L)
Weight		
1 ounce (oz)	=	28.35 grams (g)
1 pound (lb)	=	453.6 grams (g)
1 ton	=	0.91 tonne (t)
Pressure		
1 pound per square inch (lb/in^2)	=	6.90 kilopascals (kPa)
Temperature		
°C	=	$(°F-32) \times {}^5/_9$

12. Colour Plates

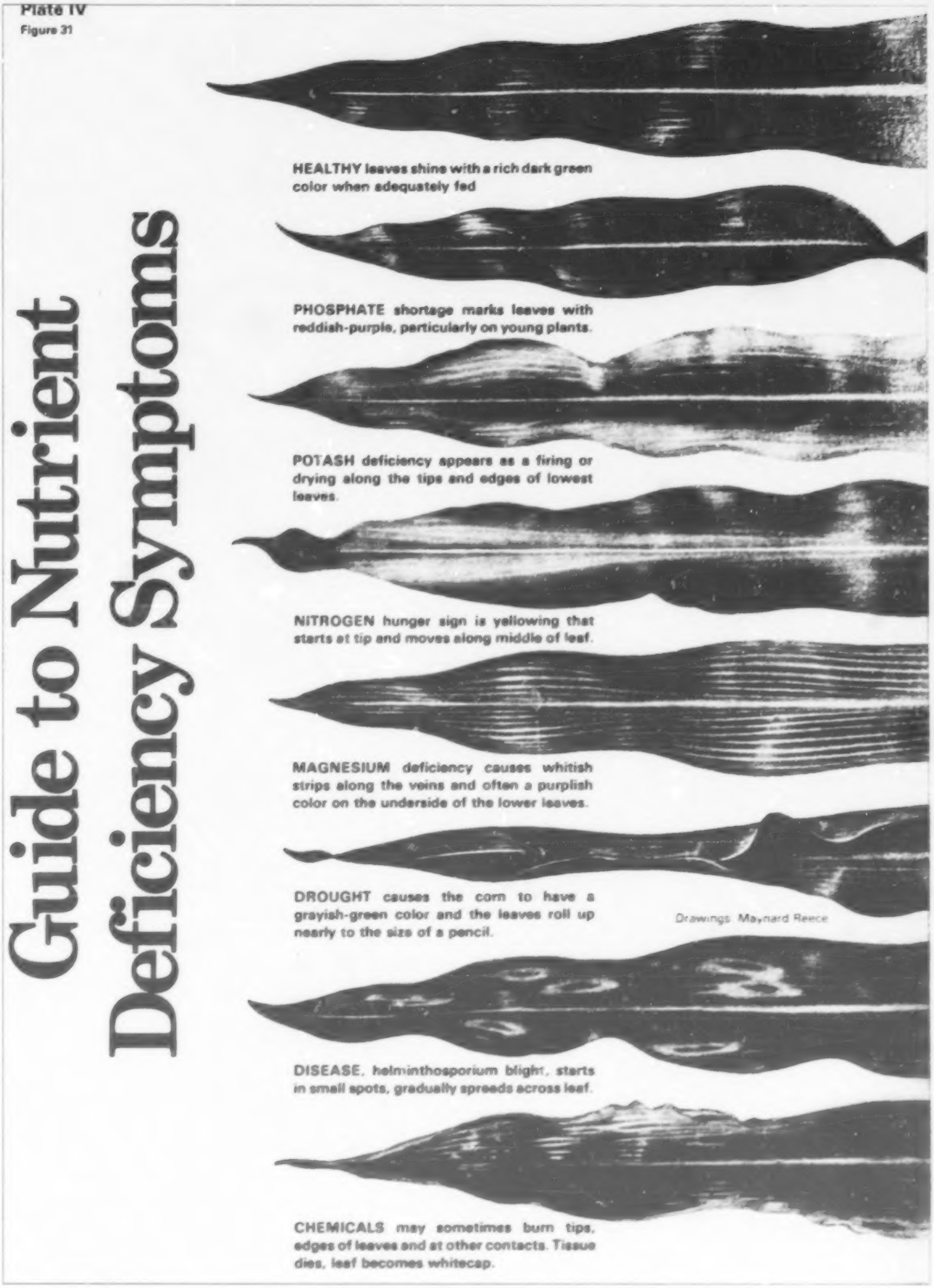


Plate IV

Figure 31

Guide to Nutrient Deficiency Symptoms

HEALTHY leaves shine with a rich dark green color when adequately fed

PHOSPHATE shortage marks leaves with reddish-purple, particularly on young plants.

POTASH deficiency appears as a firing or drying along the tips and edges of lowest leaves.

NITROGEN hunger sign is yellowing that starts at tip and moves along middle of leaf.

MAGNESIUM deficiency causes whitish strips along the veins and often a purplish color on the underside of the lower leaves.

DROUGHT causes the corn to have a grayish-green color and the leaves roll up nearly to the size of a pencil.

Drawings: Maynard Reece

DISEASE, helminthosporium blight, starts in small spots, gradually spreads across leaf.

CHEMICALS may sometimes burn tips, edges of leaves and at other contacts. Tissue dies, leaf becomes whitecap.

PLATE 1. Guide to Nutrient Deficiency Symptoms. Reprinted with permission of the *Saturday Evening Post* © 1957 (renewed) BFL&MS, Inc.

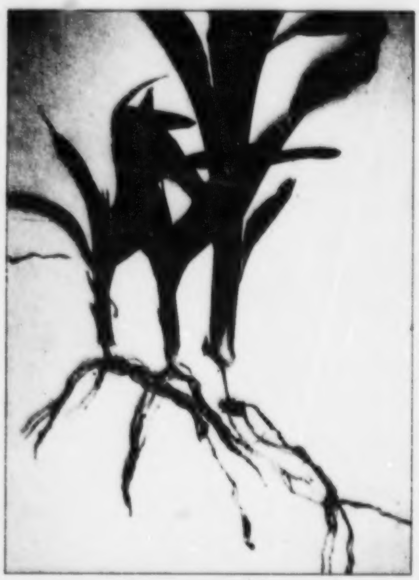


PLATE 2. Uneven planting depth. Uniform seeding depth is a critical factor in achieving uniform emergence.

PLATE 3. Purple corn. Purple leaves on corn caused by cool weather stress or root injury. This is not usually an indication of phosphorous deficiency.

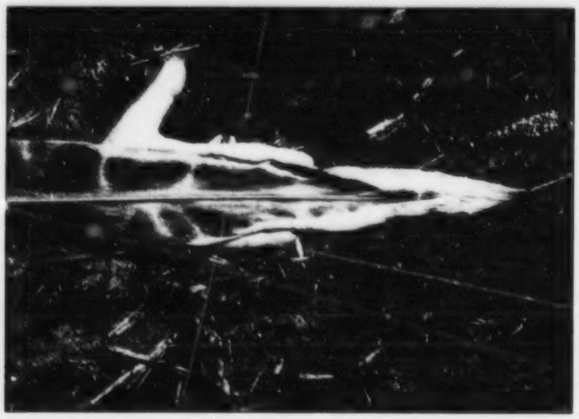


PLATE 4. Potassium deficiency shows up on lower leaves first, as yellow and browning at the leaf tip, and proceeds back along the margin of the leaf.

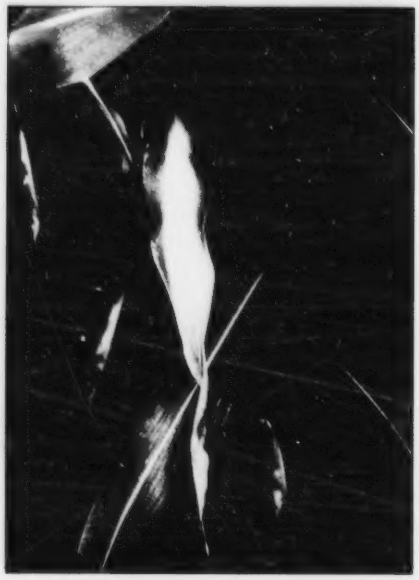


PLATE 5. Nitrogen deficiency shows up on lower leaves first. Yellowing begins at the leaf tip and proceeds down the midrib.

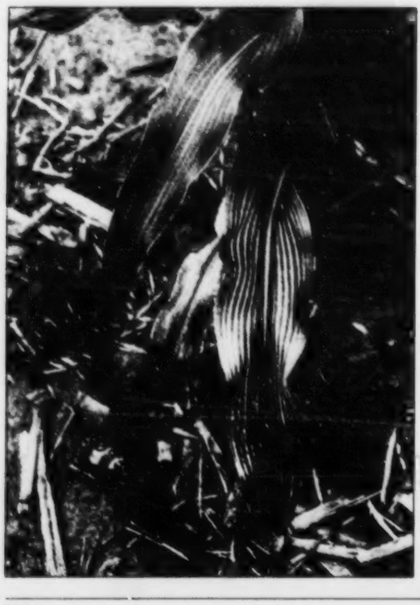


PLATE 6. Magnesium deficiency appears first as yellow striping of the lower leaves. These may turn reddish-purple later as deficiency progresses.

PLATE 7. Zinc deficiency appears as a broad white band near the base of the leaf on younger plants.

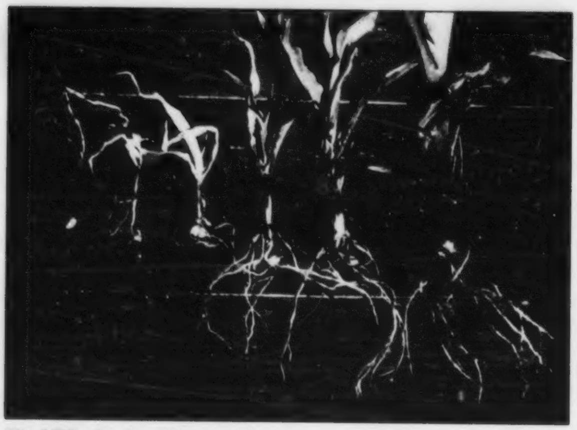


PLATE 8. Fertilizer injury burns the primary root, delaying growth until secondary roots develop. Plant emergence will be uneven.

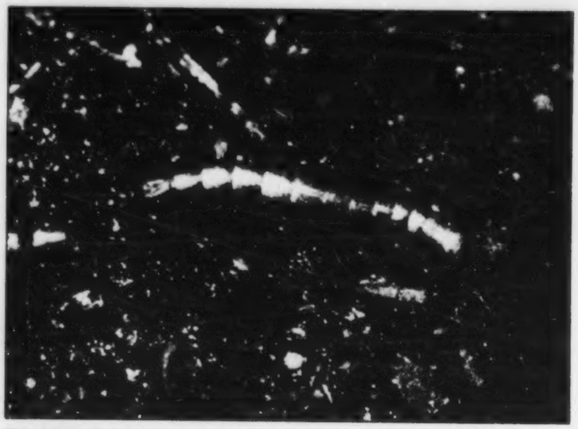


PLATE 9. Wireworms have long, cylindrical, copper-brown, hardened bodies. They affect many crops, usually when following grassy crops in the rotation.

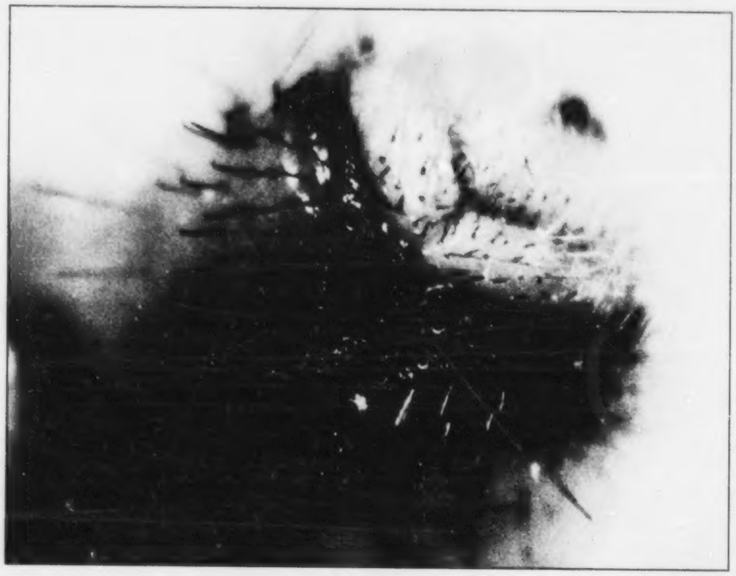


PLATE 10. European chafer larvae are white with an orange-brown head and dark posterior. They are distinguished from other white grubs by the Y-pattern of the anal bristles (rasters).

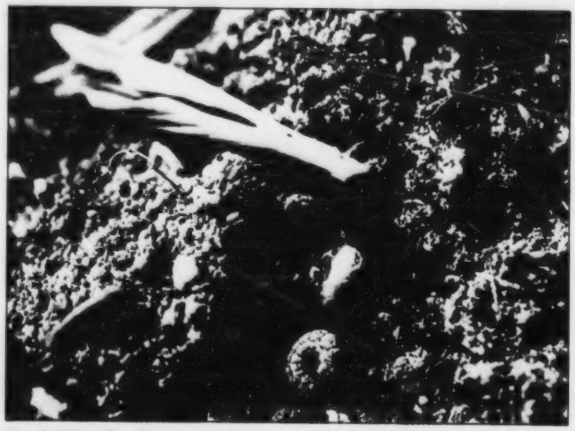


PLATE 11. Black cutworm larvae are greyish-black with a paler underside. Mature larvae are about 3.5 cm (1.25") long. Corn plant has been cut at the soil level.

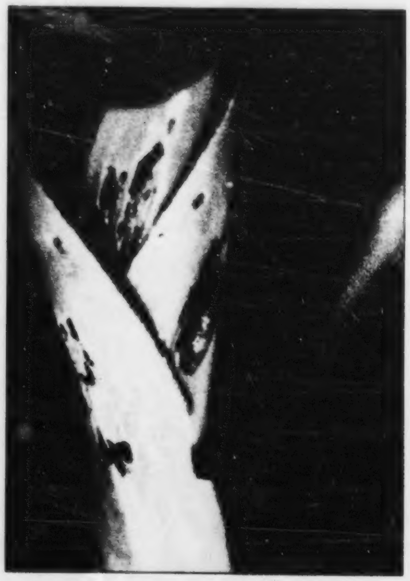


PLATE 12. Slugs are soft-bodied, legless and greyish or mottled. They have a slimy or gelatinous covering that leaves trails where they have travelled.

PLATE 13. Western corn rootworm adults are yellow to green with three wavy black stripes on their back.

PLATE 14. Northern corn rootworm adults are usually green to yellow and have no stripes.

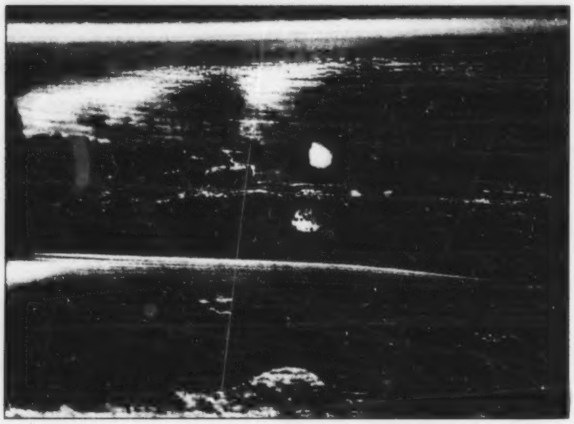


PLATE 15. European corn borer eggmass. Each eggmass can have 15–40 eggs, which are layered like fish scales.

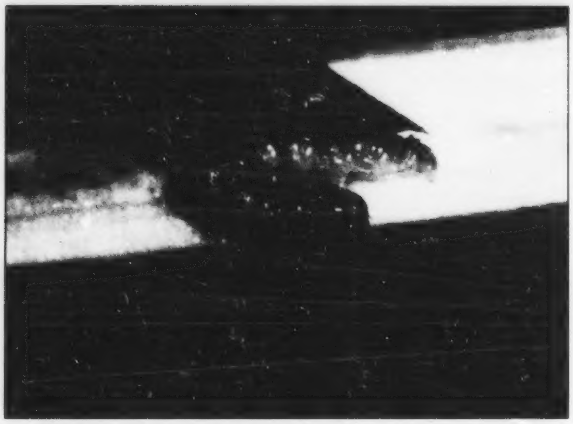


PLATE 16. European corn borer larvae are cream to pink with black heads and two black spots per abdominal segment. Stalk rots can be carried in by the larvae.

PLATE 17. Adult European corn borer moths. Female (left) is larger and lighter in colour than the male (right).

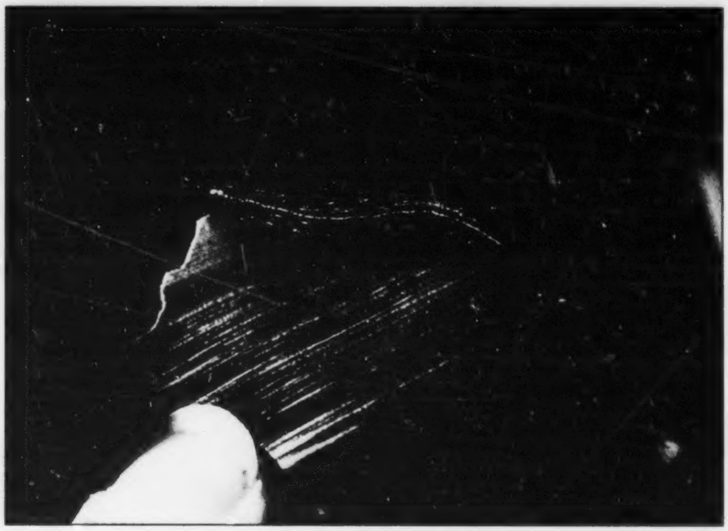


PLATE 18. True armyworm larvae have black bands at the top of each proleg and the lighter brown head.

PLATE 19. Fall armyworm larva damage on corn ear. Larvae leave entry holes on the exterior of ear. Note head is black with a white, inverted "Y" on the front.

PLATE 20. Corn earworm larva on corn ear. Larval feeding is usually concentrated at the tip of the ear.

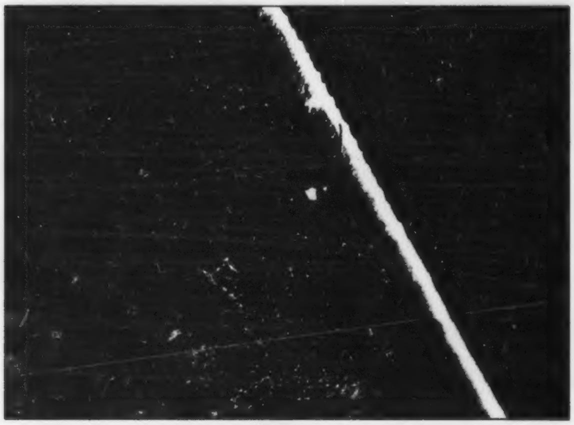


PLATE 21. Corn flea beetles leave long feeding scratches running parallel with leaf vein. Vectors of Stewart's wilt (bacterial leaf blight).

PLATE 22. Potato stem borer larva emerging from base of corn stalk. Damage is usually concentrated in border rows.

PLATE 23. Corn leaf aphids clustered on corn ear. Tassels and silks may become coated with honeydew, reducing pollination success.

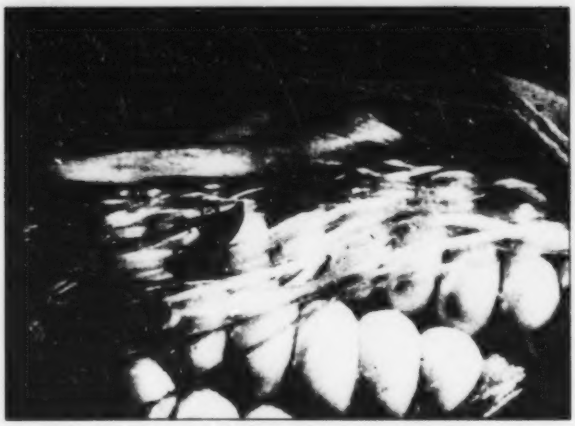


PLATE 24. Sap beetles feeding on bruised corn ear. Also known as picnic beetles. Do not cause the primary damage.

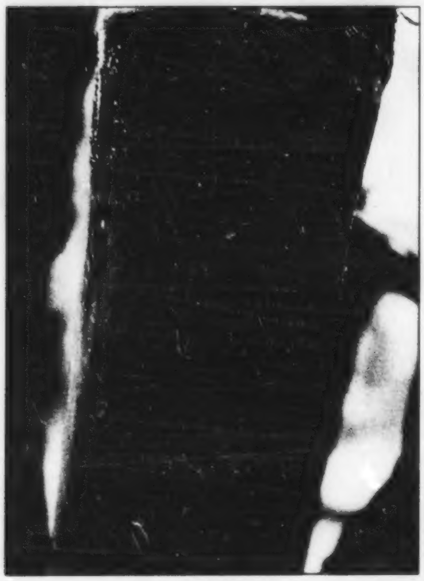


PLATE 25. Anthracnose affects both leaves and stalks. The main symptoms are leaf spots, top dieback and stalk rot.

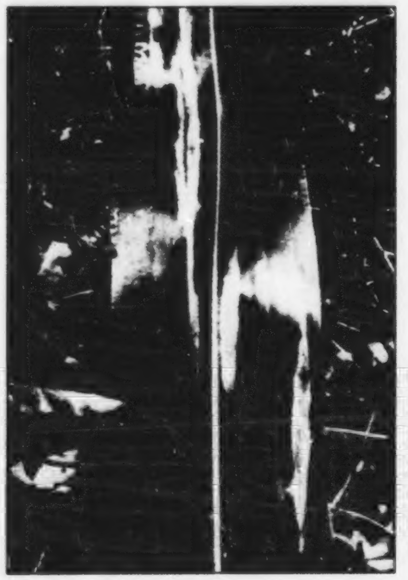


PLATE 26. Northern corn leaf blight showing long elliptical greyish-green or tan streaks.

PLATE 27. Eyespot causes round or oval leaf spots with a tan/brown centre, a brown or purple margin, and a translucent yellow halo when held up to the sun.

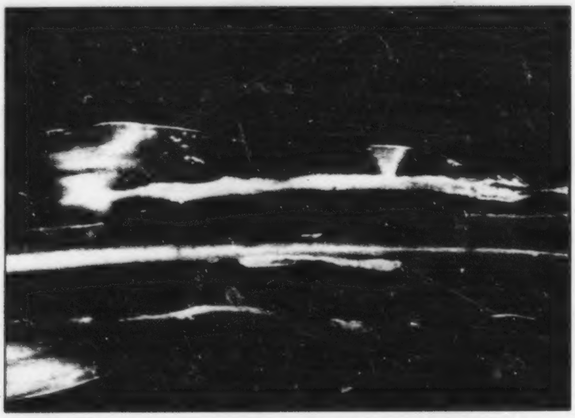


PLATE 28. Stewart's wilt (bacterial leaf blight) occurs after tasselling. Wilt phase occurs at V2 to V4 stage. Bacteria vectored by corn flea beetle.

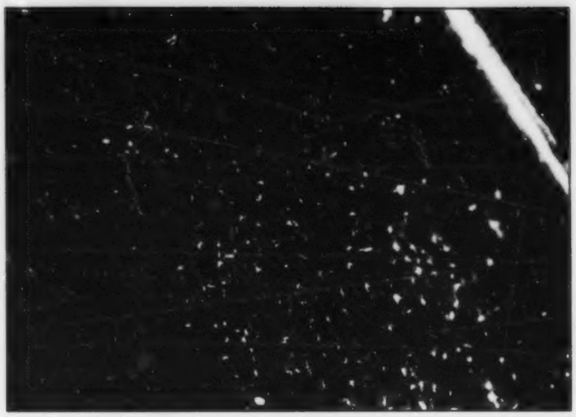


PLATE 29. Common rust symptoms range from yellow flecks to red pustules.

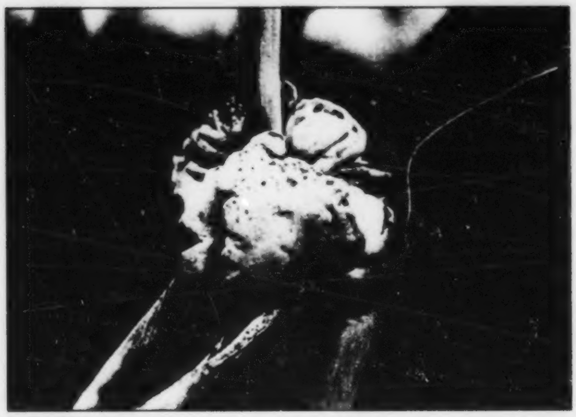


PLATE 30. Common smut incidence increases where plants have been wounded.

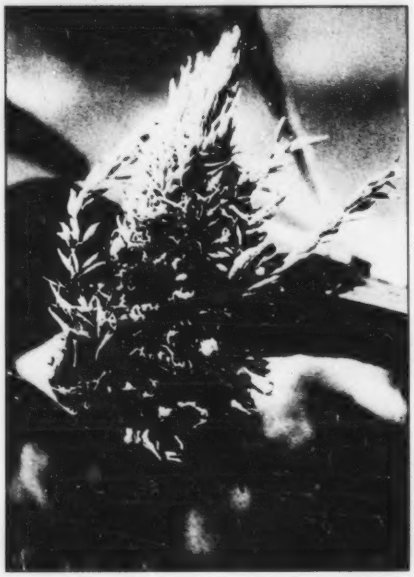


PLATE 31. Head smut can occur on the ears or the tassel.

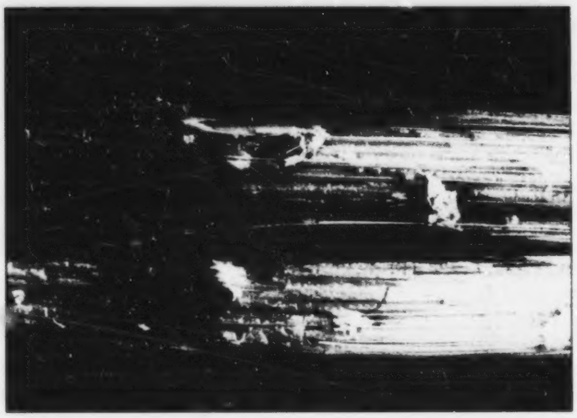


PLATE 32. Anthracnose stalk rot. Internal stalk tissue is often discoloured (black) and the pith is rotted.

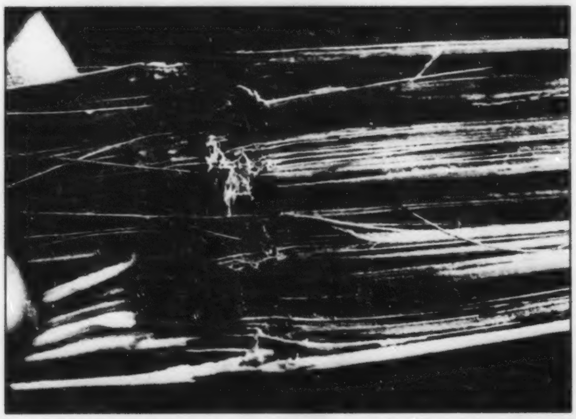


PLATE 33. Gibberella stalk rot. Inside of stalk shredded and characteristically red.

PLATE 34. Gibberella ear rot infection usually occurs from the tip down. Note the dark pink-to-red colour.

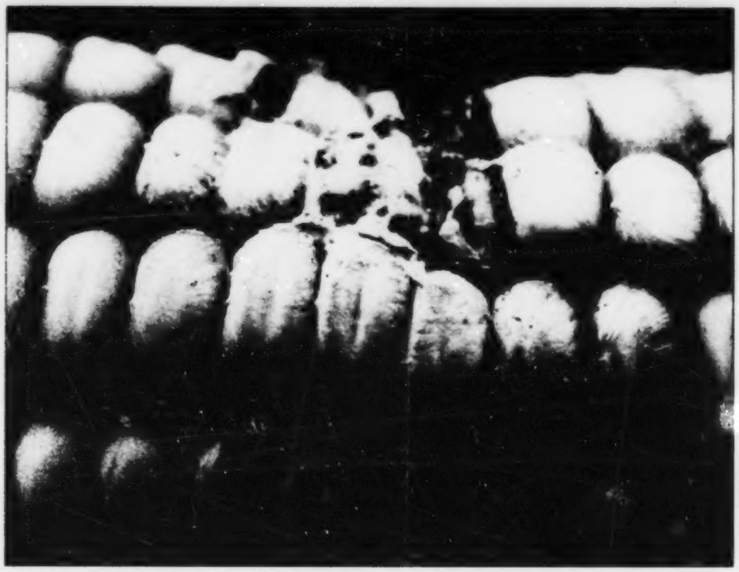


PLATE 35. Fusarium ear rot. Note the white fungal growth and the "starbursting" on the kernels.

PLATE 36. Frost injury on corn in mid-June. Smaller plants can recover, but growth in larger plants may be restricted by frost-injured dead tissue.

PLATE 37. Drought stress is most critical to yield during tasselling-to-silking stages.

PLATE 38. Hail damage is most harmful if defoliation occurs during tasselling.

PLATE 39. Bird damage on corn ears.

PLATE 40. Dinitroaniline injury on corn.

PLATE 41. Chloroacetamide injury on corn.

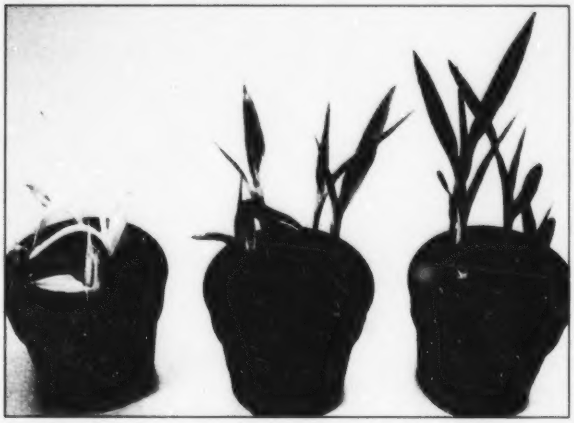


PLATE 42. Isoxaflutole injury. Bleached leaves on corn caused by isoxaflutole at 4x rate, normal field rate and check (no herbicide).

PLATE 43. "Onion leaf" symptom on corn caused by auxinic herbicides.

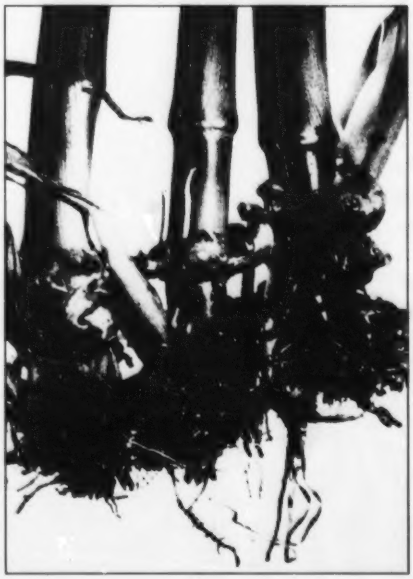


PLATE 44. Dicamba injury causes twisted brace roots on corn.

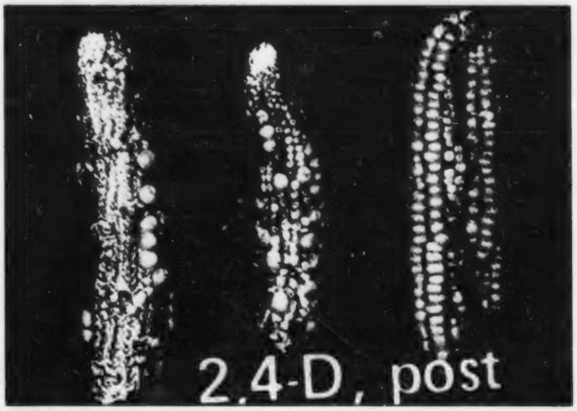


PLATE 45. Auxinic herbicide injury on ears of corn (example 2,4-D, dicamba).

PLATE 46. Bromoxynil injury on corn.

PLATE 47. ALS injury on corn showing "flash" on leaf.

PLATE 48. Group 1 graminicide (ACCase inhibitors) injury on corn.

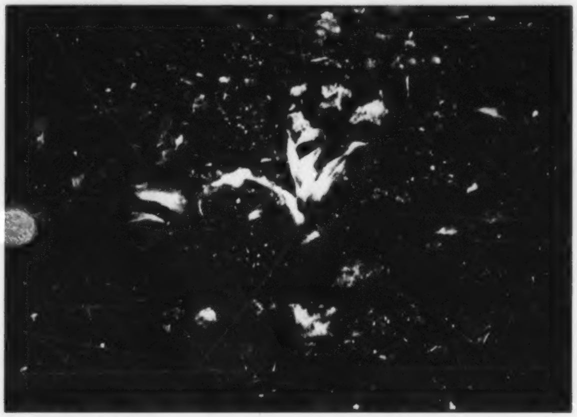


PLATE 49. Corn plants susceptible and tolerant to glyfosinate ammonium.

PLATE 50. VE and VC stages of emergence showing the hypocoytl straightening and the cotyledons unfolding.

PLATE 51. Potassium (K) deficiency appears as yellowing or browning of leaf margins on older leaves.

PLATE 52. Manganese (Mn) deficiency. Upper leaves appear pale green to almost white with green veins.

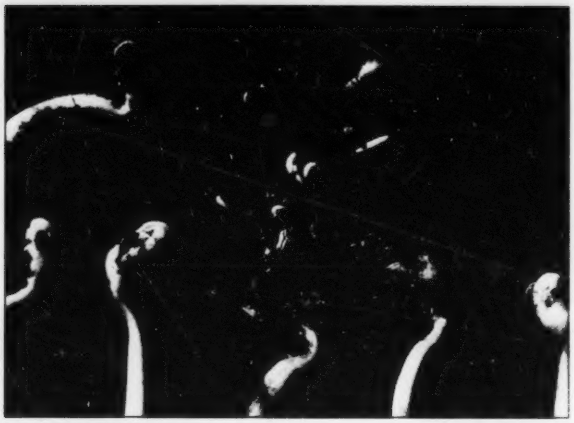


PLATE 53. Seedcorn maggots are small, headless, legless larvae that burrow into germinating seeds and weaken the seedling.

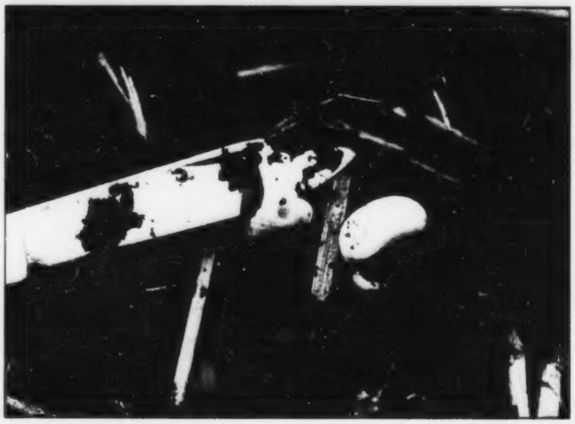


PLATE 54. Slug injury on seed. Slugs prefer high humidity, cool temperatures and debris to provide shelter from the sun.

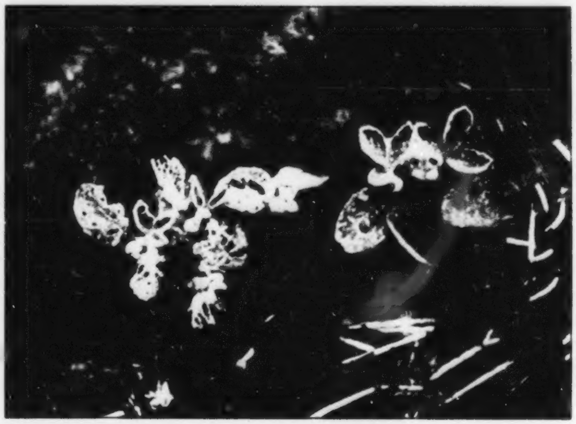


PLATE 55. Foliar damage caused by slugs. Slugs feed on all parts of the plant leaving ragged holes. Feeding on the growing point can kill the plant.

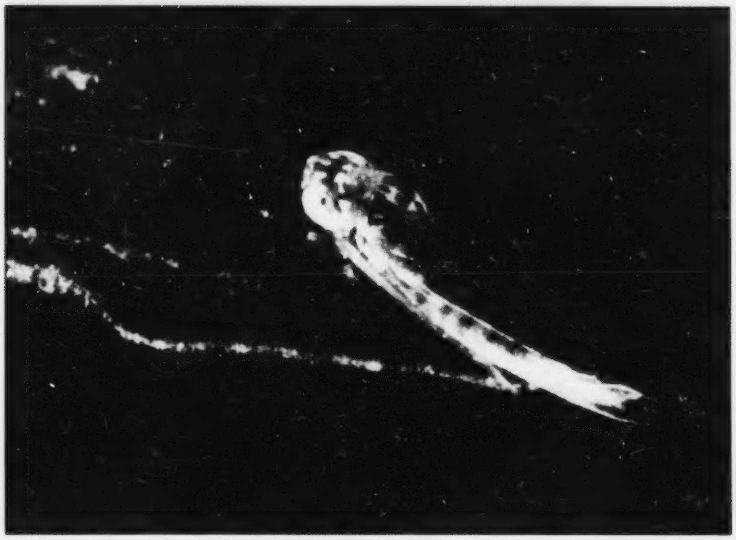
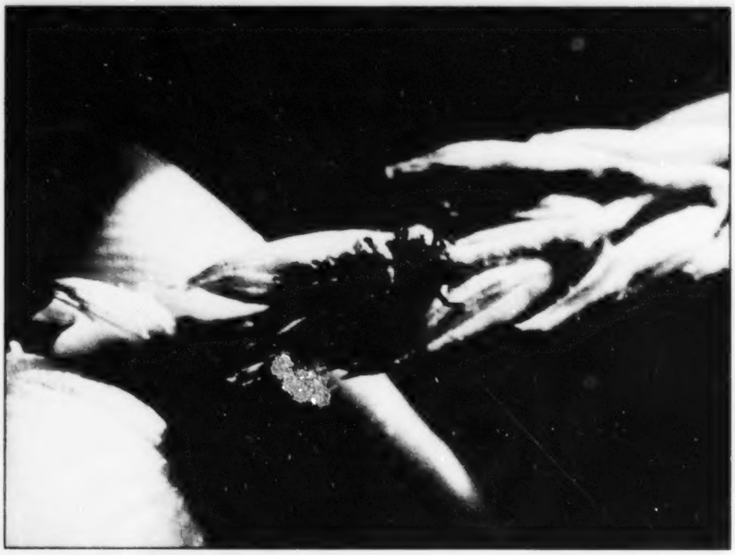


PLATE 56. Potato leafhoppers are pale green, wedge-shaped, winged insects. Immature nymphs are smaller and wingless.

PLATE 57. Soybean aphids are small and pale green and may be winged or wingless. Can be found on the underside of leaves and stems.

PLATE 58. Ladybird beetle larvae are a natural enemy of the soybean aphid.



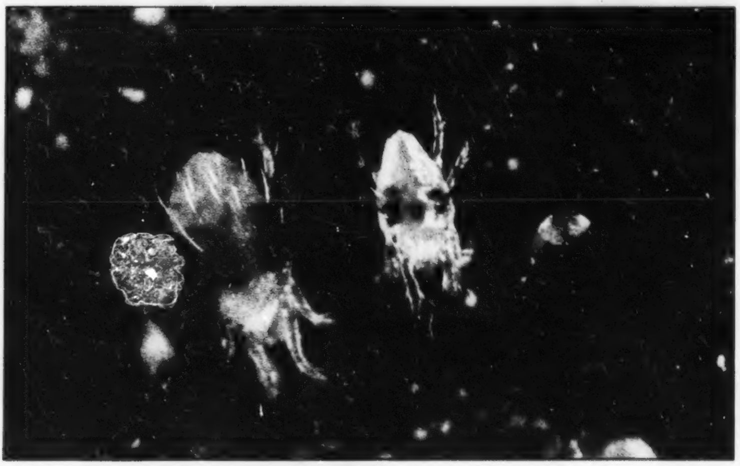


PLATE 59. Two-spotted spider mites are barely visible to the naked eye. Adults are eight-legged, yellowish-brown, with two dark spots.

PLATE 60. Spider mite injury is most visible on the underside of the leaf causing yellowing, curling and bronzing of leaves.

PLATE 61. Bean leaf beetle adults vary in colour, but always have a small black triangle visible behind the head. They may or may not have four spots.

PLATE 62. Japanese beetles have a bright, metallic green head and coppery wings tinged with green edges. Twelve white tufts of hair appear at wing boundary.

PLATE 63. Fusarium root rot causes a brown discolouration of the internal root tissue.

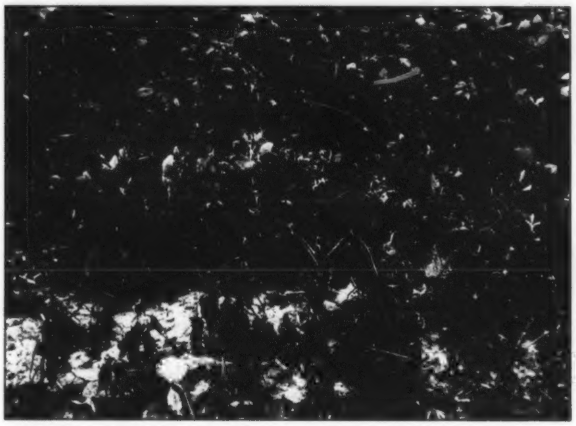


PLATE 64. Phytophthora root rot causes water-soaked lesions on seedlings and purple or dark-brown discolouration of the stem. Begins at the soil line and progresses into the lower nodes.

PLATE 65. Rhizoctonia root rot causes reddish lesions on the stem at or just below the soil line.

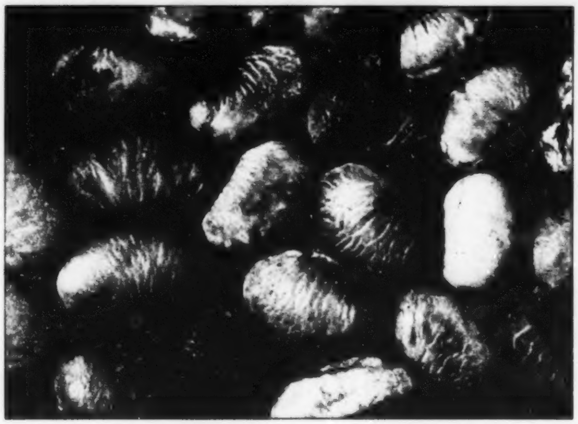


PLATE 66. Phomopsis seed mould causes fine cracks and mould, starting near the hilum, reducing quality and seed vigour.

PLATE 67. Phomopsis pod and stem blight symptoms include small, black, raised dots or bumps arranged in rows or islands on the stem.

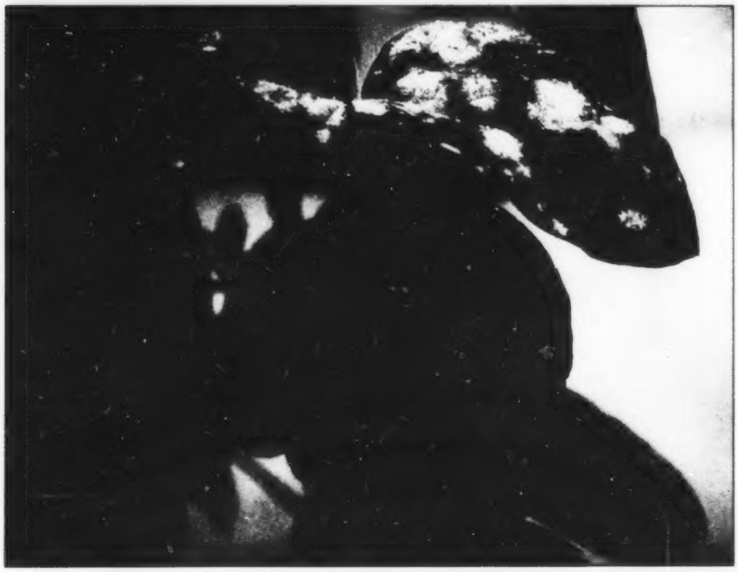


PLATE 68. Powdery mildew appears as a white powder on the upper surface of the leaf.

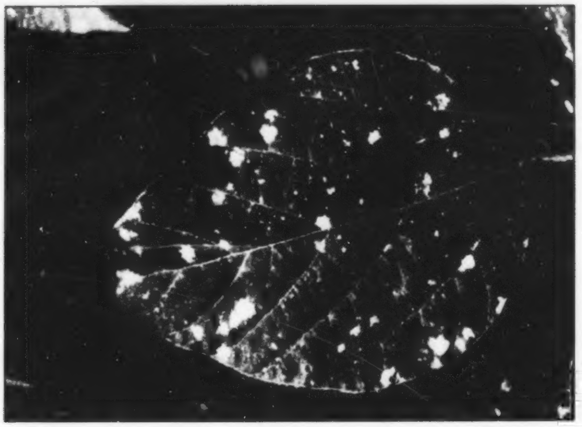


PLATE 69. Downy mildew appears as yellow-to-brown spots on the leaf with pale blue-to-grey mildew on the lower leaf surface.

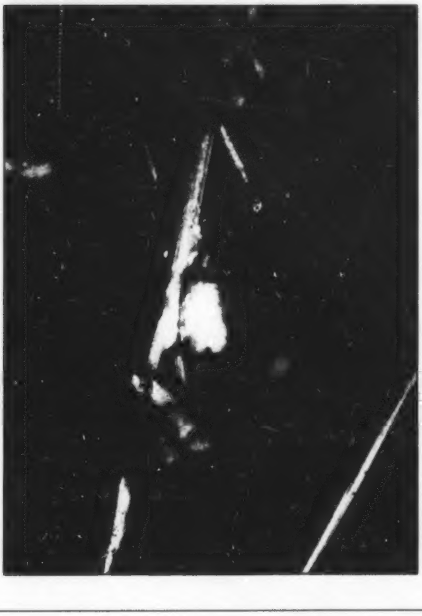


PLATE 70. White mould (*Sclerotinia*) produces a white, cotton-like fungal growth on diseased stems.

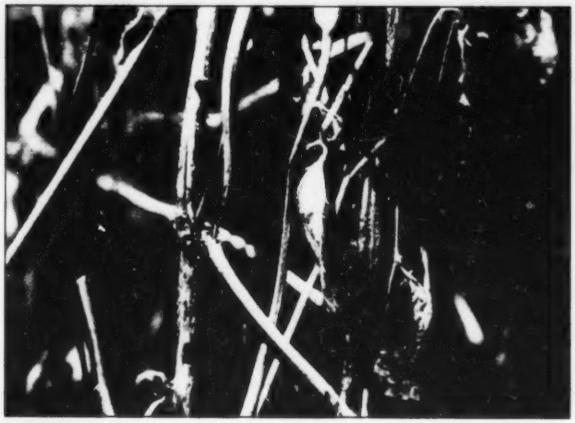


PLATE 71. Stems infected with white mould die, and small black bodies (sclerotia) can be seen on the stem.

PLATE 72. Plants infected with soybean cyst nematode can be stunted, with yellowish leaves. Frequently in circular patterns in the field.

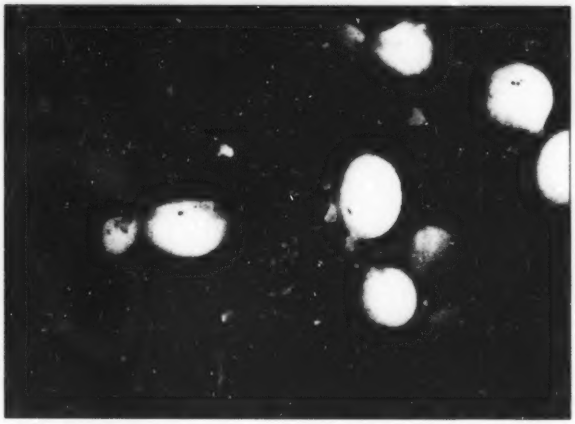


PLATE 73. Soybean root with SCN cysts. Yellow-brown, lemon-shaped cysts (pin-head size) are produced on the roots of plants infected with soybean cyst nematode.

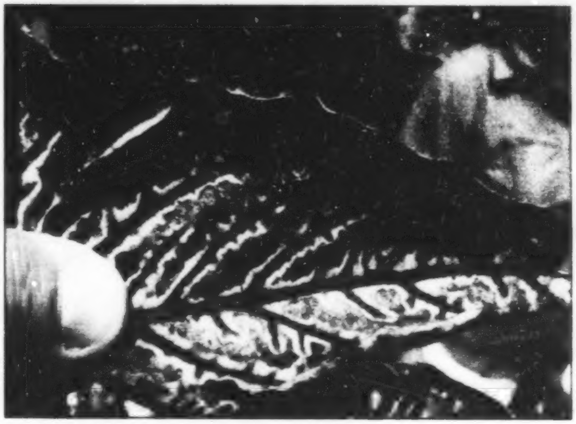


PLATE 74. Plants infected with sudden death syndrome wilt and die quickly. Interveinal chlorosis and necrosis of upper leaves may occur.

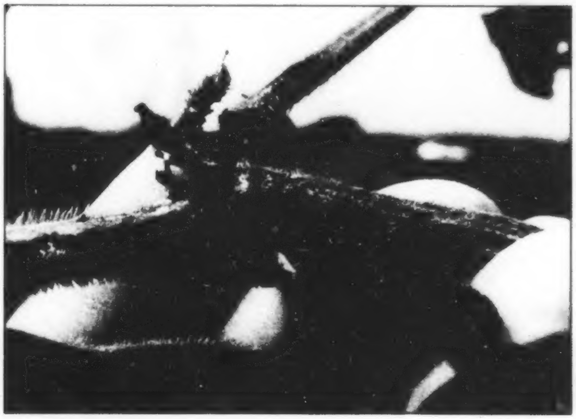


PLATE 75. Stem canker causes plants to wilt suddenly with brownish-red lesions near lower nodes.

PLATE 76. Soybean mosaic virus symptoms include distorted and puckered leaves. Plants may be stunted. Vectored by soybean aphids.

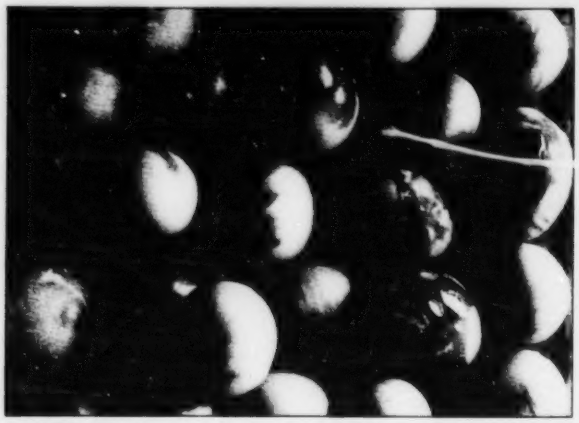


PLATE 77. Soybean mosaic virus can cause brown or black discolouration of the seed and streaks near the hilum.

PLATE 78. Frost injury. If frost damages the growing point, but not the stem, the plant may recover by new growth emerging at the leaf axils.

PLATE 79. Hail damage. Soybeans are most vulnerable to hail damage during flowering and pod fill.

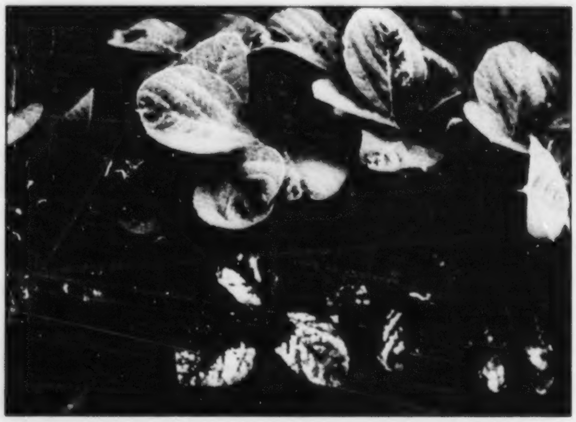


PLATE 80. Triazine injury. Injury on lower leaves of soybeans showing yellowing and dead tissue between the veins.

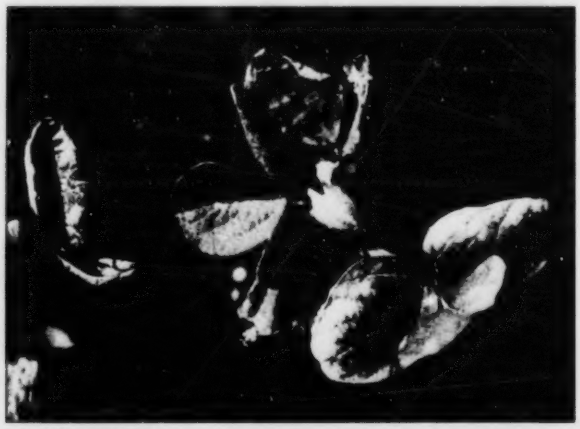


PLATE 81. Triazine injury on soybeans through root uptake or more commonly by splash-up on the leaves.

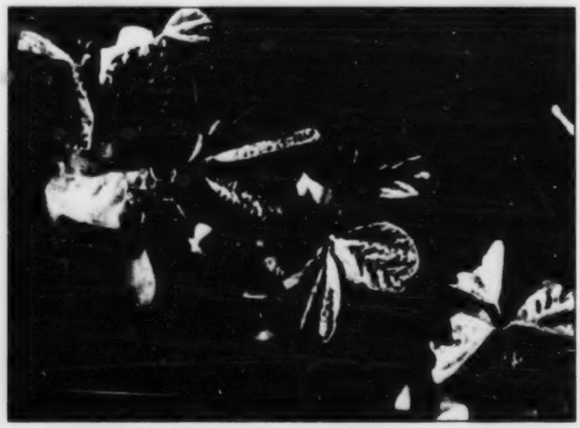


PLATE 82. Chloroacetamide injury on soybeans showing shortened midrib causing "heart-shaped" leaves.

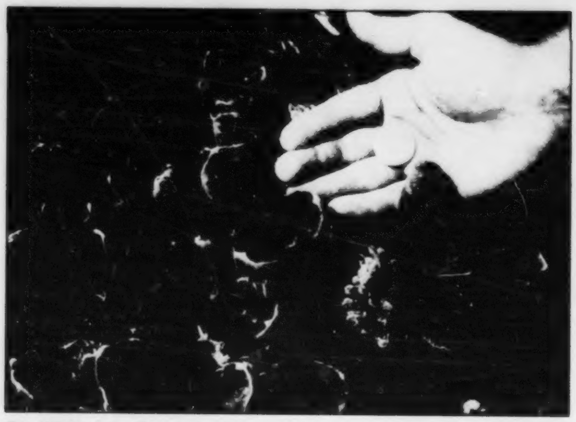


PLATE 83. Auxinic herbicides such as dicamba or 2,4-D cause leaf puckering and twisting of stems.

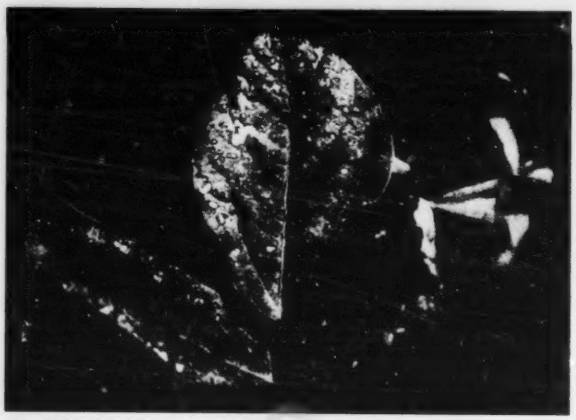


PLATE 84. Diphenylether herbicides cause contact burning injury on the leaves, but newer leaves will not be affected.

PLATE 85. Bentazon injury on soybeans.

PLATE 86. ALS herbicide injury showing reddish veins on underside of soybean leaf.

PLATE 87. Potassium (K) deficiency is indicated by small light dots near margins of the leaflets.

PLATE 88. Boron deficiency appears on the upper leaves, becoming yellow to red and stunting growth.

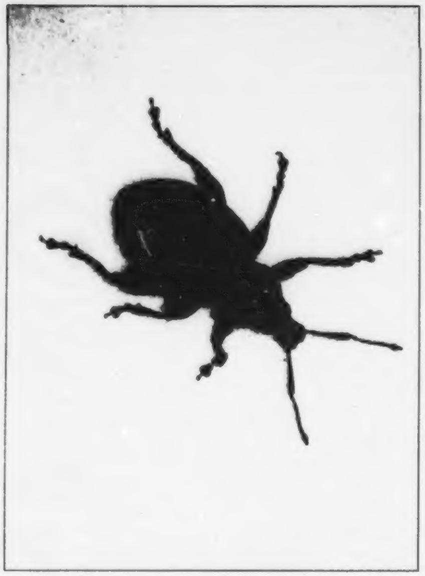


PLATE 89. Alfalfa snout beetle adults are approximately 12 mm long and cannot fly.

PLATE 90. Alfalfa snout beetle larvae girdle the taproot or gouge its surface, leaving deep spiral grooves. Larvae are white and legless and have a reddish-brown head.

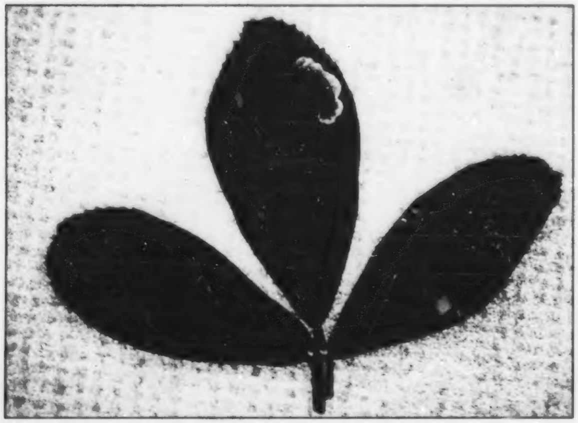


PLATE 91. Alfalfa blotch leafminer larvae feed inside the leaflet, creating tunnels or mines between the top and bottom layers of the leaf.

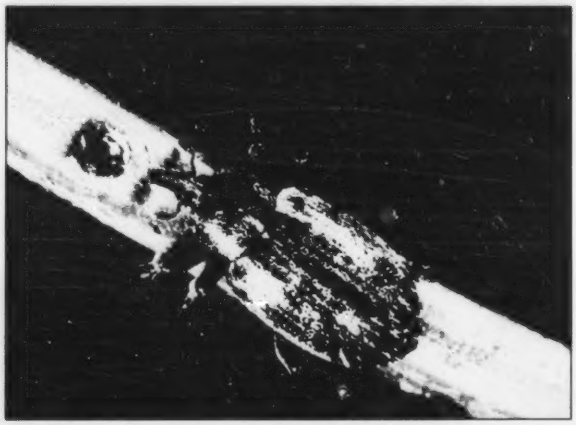


PLATE 92. Alfalfa weevil adults are about 8 mm long. Note the dark stripe running along the back.

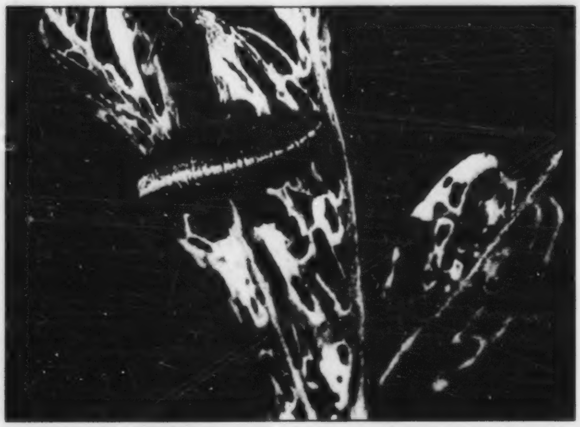


PLATE 93. Alfalfa weevil larvae feed on leaves, causing skeletonization. Note: Larvae have black heads.

PLATE 94. Potato leafhopper injury is most severe in new seedlings and in young regrowth.

PLATE 95. Verticillium wilt initially affects each stem, causing stems to wilt, curl inward, become bleached. Growth is stunted.

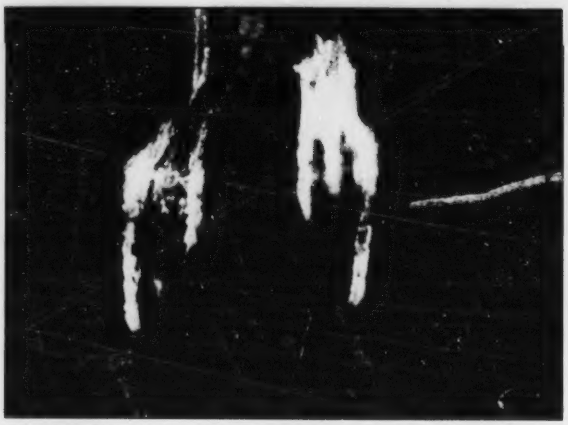


PLATE 96. Phytophthora root rot infection begins as the plants emerge. Infected seedlings are stunted and begin to wilt.

PLATE 97. Fusarium root rot appears as rusty, dark brown strands in the xylem of the root.

PLATE 98. Leptosphaerulina (lepto) leaf spot starts as small dark spots that enlarge until spots join together. Spots will have a tan centre and a yellow halo.

PLATE 99. Alfalfa heaving is caused by freeze/thaw cycles of early spring, lifting the crown up.

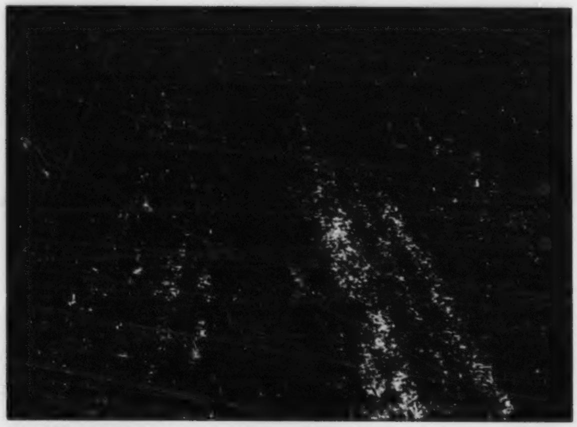


PLATE 100. Corn row syndrome of winter wheat caused by fertilizer or pesticide carryover in the rows of previous crops.

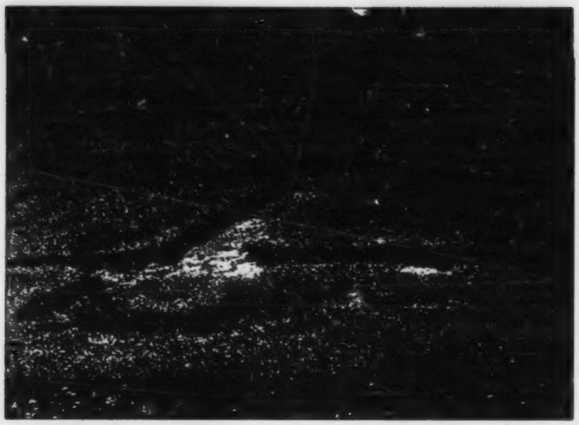


PLATE 101. Lodging due to overlaps and/or excessive rates of nitrogen fertilizer.

PLATE 102. U.A.N. 28% leaf burn. Applications of 28% U.A.N. fertilizer can burn leaves and reduce yields.

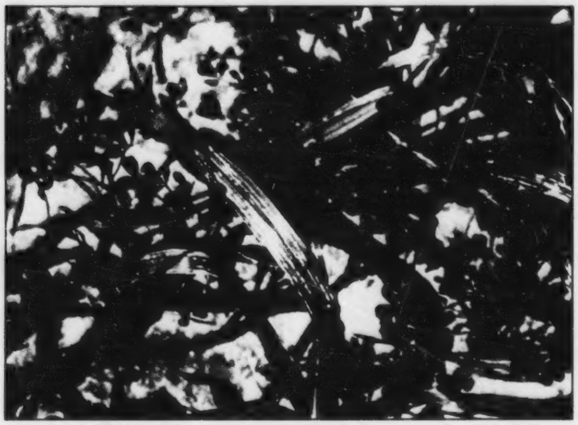


PLATE 103. Manganese deficiency on oats looks like irregular, oval, grey spots.

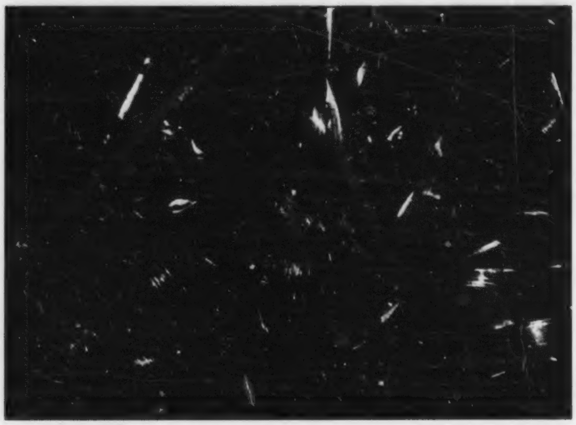


PLATE 104. Manganese deficiency on winter wheat (pale-yellow interveinal stripes on the leaf) occurs most frequently on high pH, sandy soils or on organic soils.

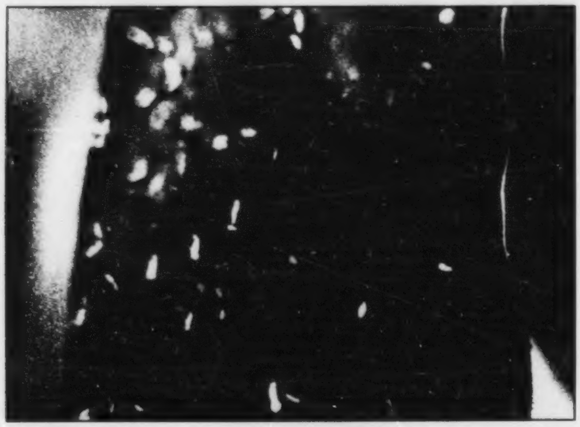


PLATE 105. Cereal aphids are dull olive-green with patches of red-orange near the rear of the abdomen.

PLATE 106. Cereal leaf beetle larvae are yellowish, but this colour is obscured by a black deposit of fecal material making it slug-like in appearance.

PLATE 107. True armyworm larvae are 4 cm long (1½ in.) when fully grown. Dark bands at the top of each proleg are the distinguishing features.

PLATE 108. Seedling blights are caused by several organisms. Many seedlings fail to emerge or emerge looking yellow with brown or red-brown rot on the lower stem.

PLATE 109. Take-all is noticeable at heading. Head, stem and leaves all become bleached due to this root disease.

PLATE 110. Eyespot produces elliptical, eye-shaped lesions on the lower internode near the soil line.

PLATE 111. Snow mould appears when the snow melts after long periods of snow cover. Dead plants are slimy, brown and rotted.

PLATE 112. Leaf rust affects the leaf blades and sheath. Small, yellow-brown spots contain orange to orange-brown spores.

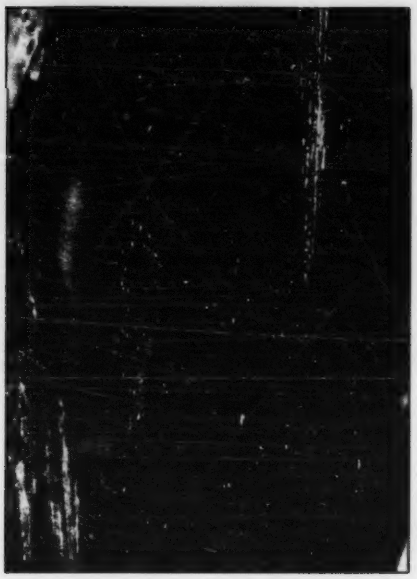


PLATE 113. Stem rust can be found on the leaf, sheath, stem and head.

PLATE 114. Barley yellow dwarf virus (BYDV) is transmitted by aphids. Symptoms are stunting and yellowing with reddening or purpling of leaf tips.

PLATE 115. Red leaf is the main symptom of BYDV on oats.

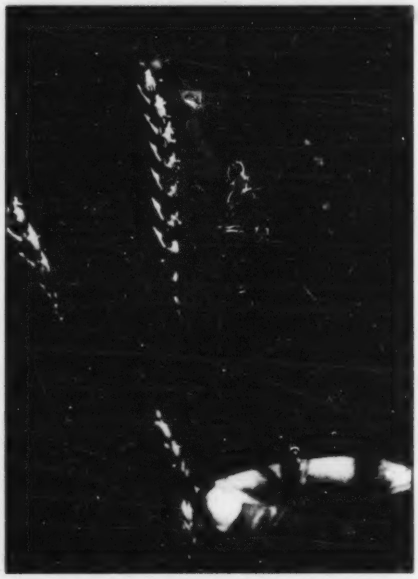


PLATE 116. Loose smut causes the kernels to be replaced by dry, black masses of spores, visible soon after the head emerges.

PLATE 117. Powdery mildew produces a white-to-grey fungal growth on the lower leaves and moves up the plant.

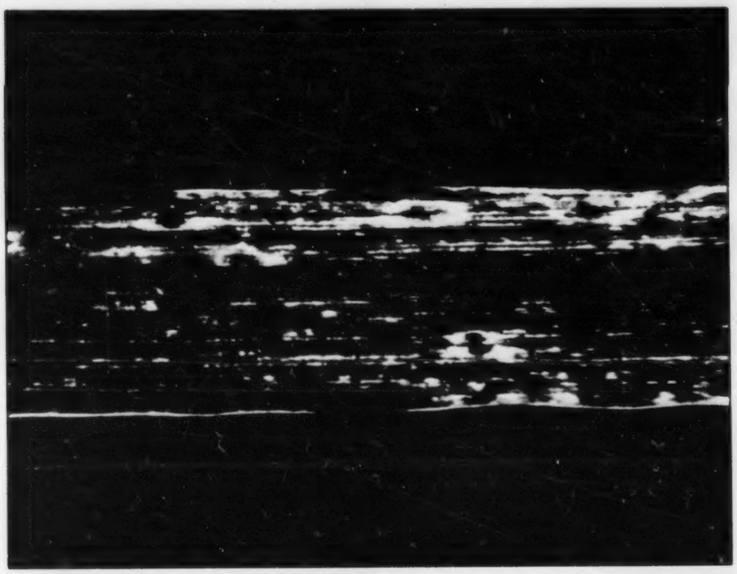


PLATE 118. Septoria leaf spot appears as small, light green-to-yellow spots that elongate to form reddish-brown lesions.

PLATE 119. Septoria glume appears as small, oval, grey-to-brown spots on the leaves and purplish-brown areas on the glumes.

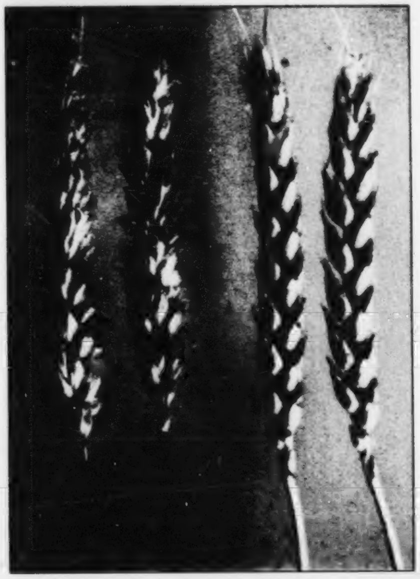


PLATE 120. Fusarium head blight bleaches all or part of the head. Typically, the stem remains green.

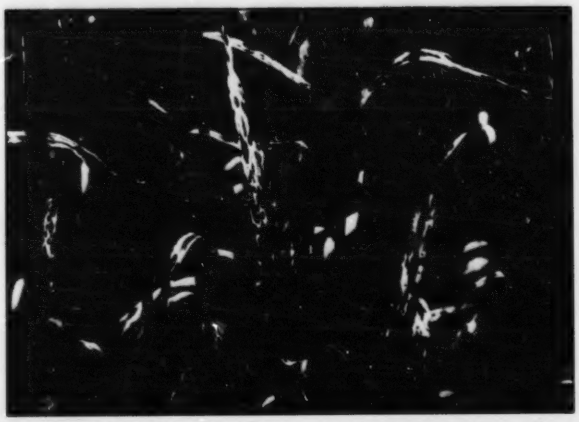


PLATE 121. Spot blotch causes brown spots on the leaf and can cause seedling blight with rot appearing on the lower stem.

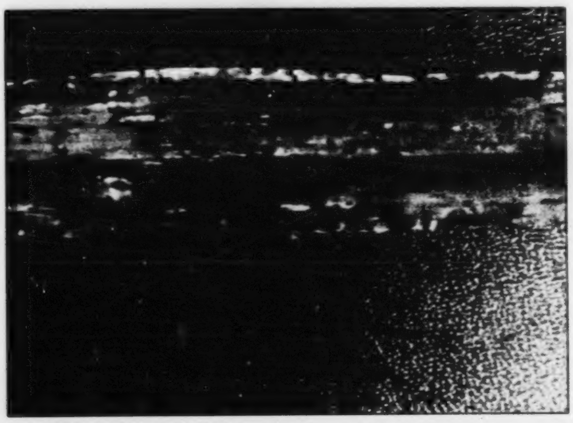


PLATE 122. Net blotch starts as light green or brown spots, enlarging, with lines appearing to give a "net" appearance.

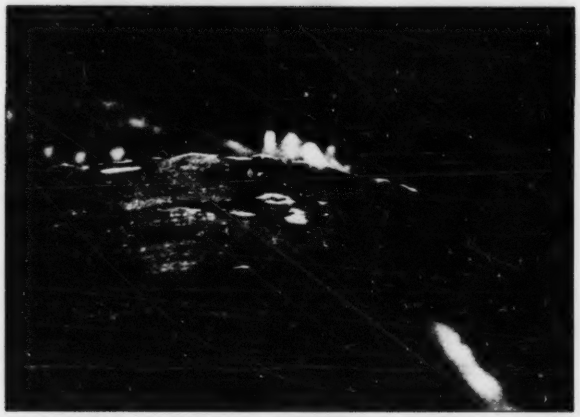


PLATE 123. Scald appears first as water-soaked, greyish-green spots turning to tan spots with brown margins.

PLATE 124. Frost heaving of winter wheat is caused by freeze/thaw cycles of early spring lifting the crown up.

PLATE 125. Atrazine injury frequently shows up most in the overlaps (and along the headlands) of previous herbicide applications.

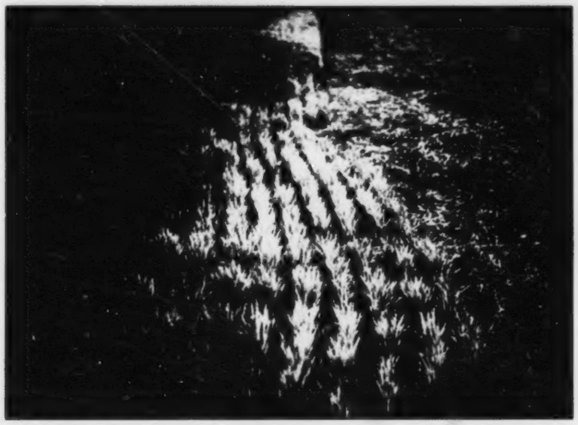


PLATE 126. Glyphosate overspray injury. Glyphosate can drift into the border of susceptible crops.

PLATE 127. Bromoxnyl herbicides can cause browning of the leaf tips.

PLATE 128. Green cloverworm larvae are pale green and have two white, longitudinal stripes running along the length of the back.

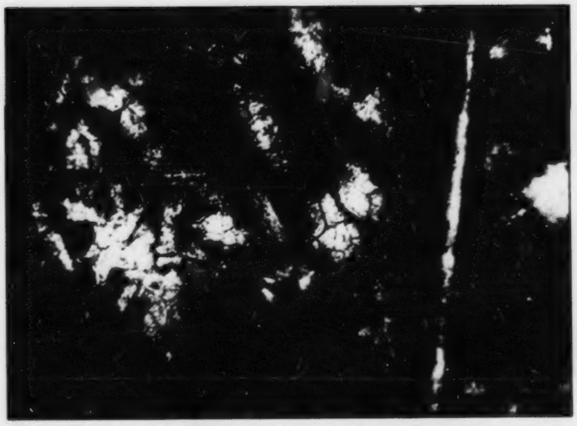


PLATE 129. Mexican bean beetle adult and larva. The beetles have 16 small black spots on their coppery-red back. Larva have black-tipped spines along back.

PLATE 130. Bacterial blight begins as small, water-soaked spots on the leaflet that join together to form large, brown, dry areas between the veins, surrounded by a yellow border.

PLATE 131. Anthracnose causes round or angular lesions on the leaves, stem and pods that are sunken with a black ring on the edge.

PLATE 132. Root rot caused by several organisms showing stunting, wilting, discoloured roots, etc.

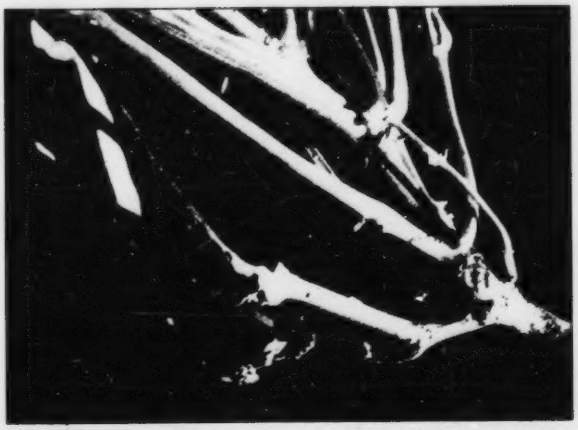


PLATE 133. White mould (Sclerotinia) initially infects older flowers and dead leaves. Eventually spreads to healthy pods, leaves and stems.

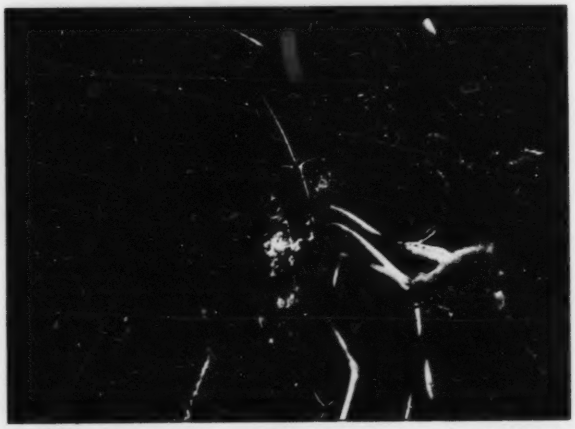


PLATE 134. White mould sclerotia are hard, black bodies produced on the surface or inside the stem and pods.

PLATE 135. Ozone (bronzing) injury. High levels of ozone can injure the leaves and cause bronzing of the upper leaf surface.

PLATE 136. Quizalofop-p-ethyl herbicide injury. Symptoms appear as white-to-yellowish flecking of leaves.

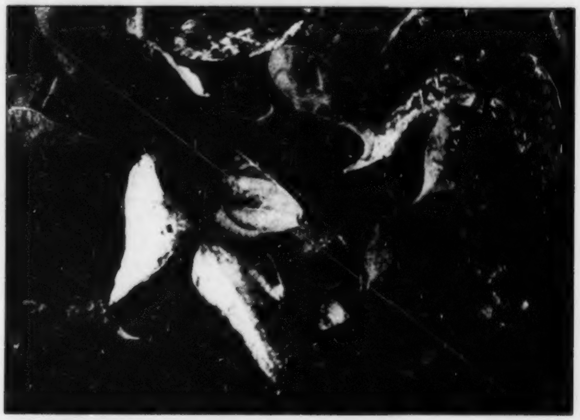


PLATE 137. ALS injury on white beans. Symptoms appear as leaf yellowing in upper or lower portions of plant. Plants may also become stunted.

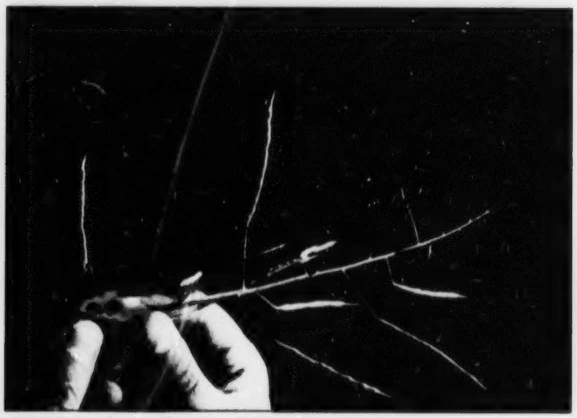


PLATE 138. Heat blast. Hot temperatures during flowering (especially of spring varieties) can cause heat blast and reduce seed yields.

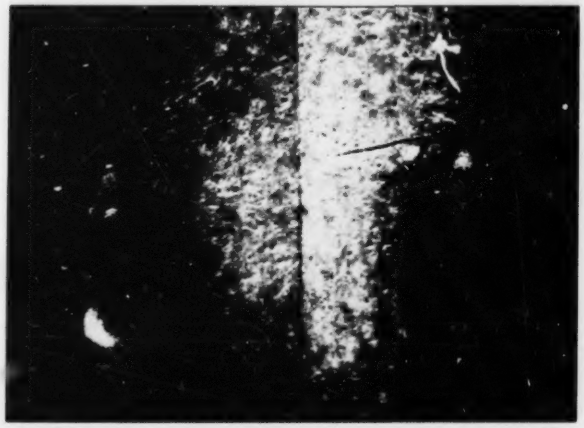


PLATE 139. Striped (left) and crucifer flea beetle adults. Flea beetle injury can be severe during first three weeks after emergence.

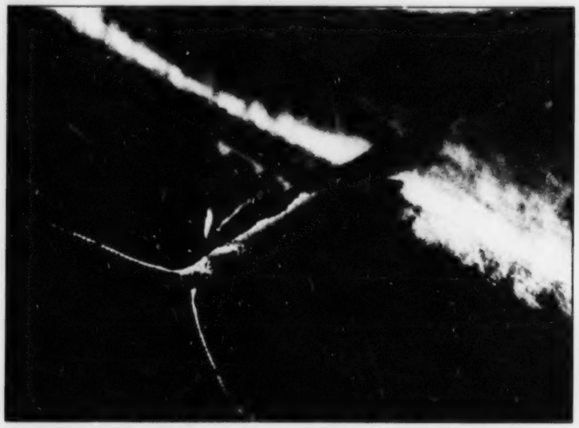


PLATE 140. Diamondback moth adult is best identified by the white, diamond-shaped markings along its back when the wings are at rest.

PLATE 141. Diamondback moth larvae are light green-to-yellowish-green with a brown head. Larvae will wiggle backwards when disturbed.

PLATE 142. Blackleg causes round-to-irregular, white-to-buff lesions containing many black dots (pycnidia).

PLATE 143. Blackleg spreads to the stem, producing a canker that girdles the lower stem.

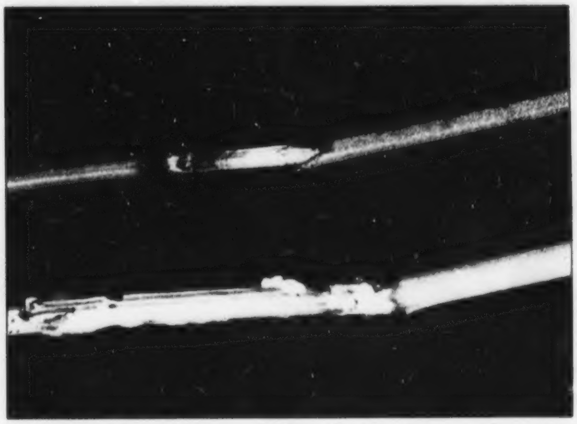


PLATE 144. White mould (Sclerotinia stem rot) causes white (bleached) stem lesions and hard black bodies in the stems.

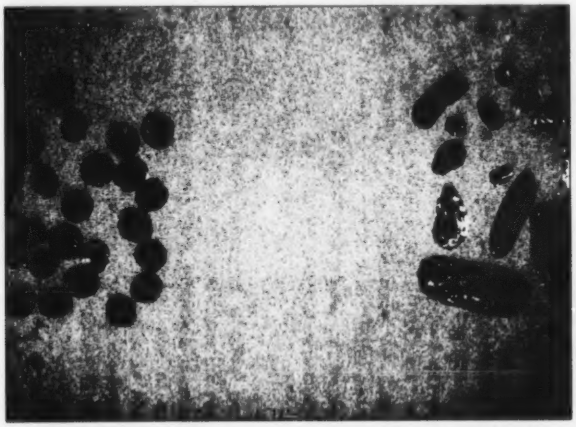


PLATE 145. White mould on seed. The black bodies of white mould are sometimes found in the seed at harvest.

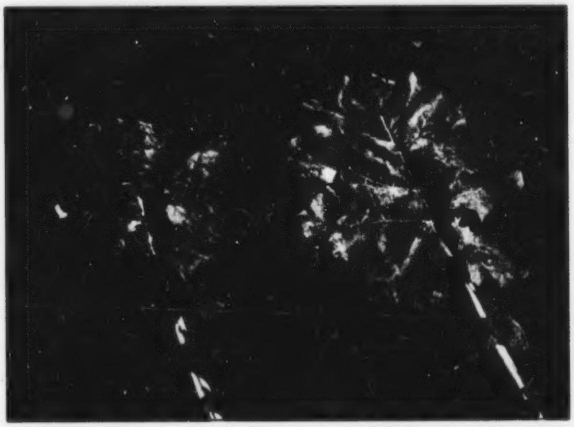


PLATE 146. Turnip mosaic virus (TMV) causes leaf mottling and wrinkling or puckering of leaves. Can cause yellowing and stunting.

PLATE 147. Sunflower white mould causes basal stem rot, mid-stem infections and head rot in sunflowers.

PLATE 148. Insect probe for stored grain is inserted into grain to trap insects.

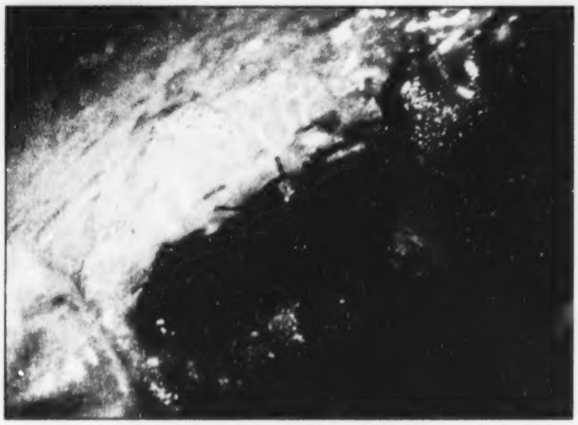


PLATE 149. Rusty grain beetle adults have antennae as long or longer than their head and thorax combined.

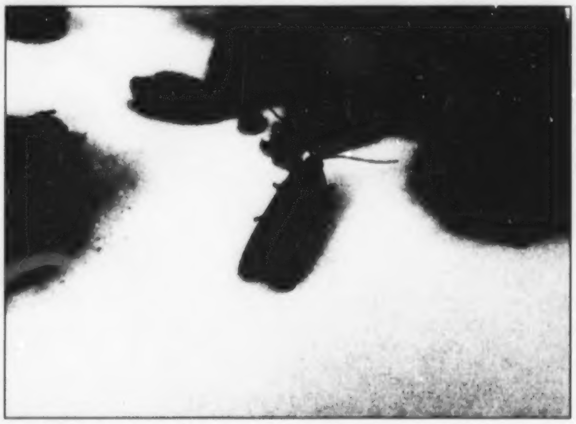


PLATE 150. Indian meal moths leave webbing on the top of the grain pile.

PLATE 151. Granary weevil is a snout beetle that has oval pits on the surface of the thorax.

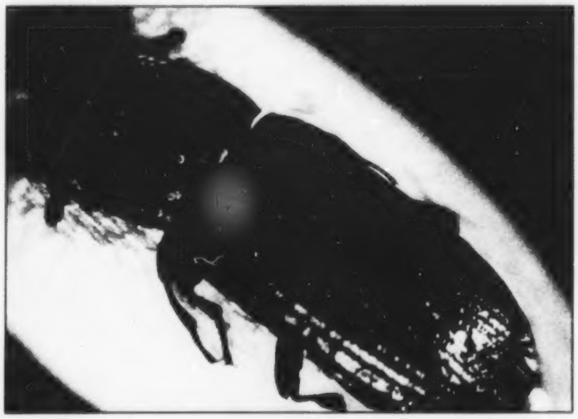


PLATE 152. Lesser grain borer's head is turned downward and covered by a large hood (prothorax). A musty odour is often associated with this pest.